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OF

Electrical Engineers

Volume XXVI.
Number 1

January, 1907

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Volume XXVI.
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OF THE

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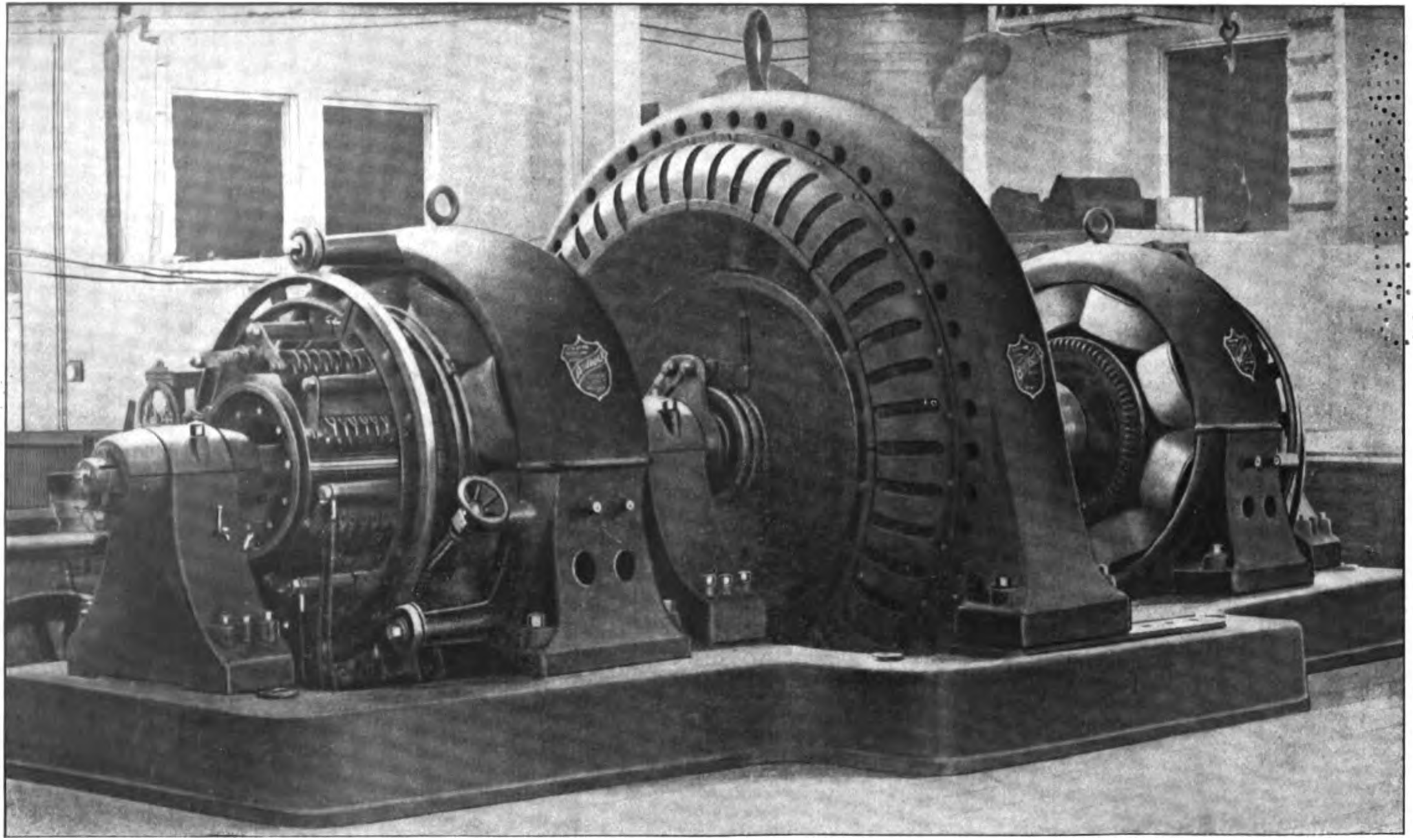

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Subscription. United States, Canada, Mexico and Cuba, $5 per year.
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Subscriptions must begin with January issue.

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Vol. XXVI. **January, 1907.** No. 1.

Transfers

RECENT circulars distributed by committees have elicited replies indicating that certain unsuccessful applicants for transfer to the grade of Member are dissatisfied with the results. In a general way it may be stated that these applicants have not submitted proper records of their engineering experience. One of the important qualifications of an engineer is that he should be able to prepare specifications or reports of his proposed work, or of investigations in behalf of a client. He should be able to judge of his own qualifications, and specify the important work he has done, and for which he was responsible. Many applicants rely upon their references to give this information, and this is frequently done. The intention is, however, that the applicant should personally record not only his electrical engineering experience, but indicate the periods of time occupied in carrying out the work. The requirements of the Constitution are simple, and if the applicant can comply with them he is in a certain sense more competent from his own knowledge to determine his qualifications than is the Board of Examiners which depends chiefly upon the records placed before it. The impression that appears to have prevailed in the past—that the decision of the Board was a mere perfunctory proceeding, has gradually been replaced by a belief that it is too rigid in its interpretation of the Constitution. If Associates will indulge in a serious contemplation of their records before filing their applications, they will in most cases avoid delay and annoyance, and greatly facilitate the work of the Board of Examiners.

Science Abstracts

ONE of the early undertakings of the Institute was a general index to current electrical literature. There were a few members who had commenced the preparation of such an index, for their personal use, but soon realized that it was a serious task and suggested that it was a proper function for the Institute. The work was begun and carried on through publication in the monthly issues of the TRANACTIONS. It was, however, too much of a burden for the voluntary individual efforts of a single person, and it was abandoned. Experience showed that it was needed very much by a few engineers, but a large number either cared little for it or preferred to depend upon their individual efforts. Since that time others have begun similar publications. The best of these is known as Science Abstracts, which is issued in two series of monthly parts, covering the fields of Physics and Electrical Engineering. Its publication was begun in 1898 under the auspices of the Institution of Electrical Engineers, with the coöperation of other learned societies. Through an arrangement made in 1902, members of the American Institute of Electrical Engineers have been permitted to subscribe for this publication at a reduced rate. If its value were more generally appreciated, no doubt the number of

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subscribers would be greatly increased, and to this end further information is given in the advertising pages of this issue. To avoid the necessity of making foreign remittances, the Secretary has been authorized to receive subscriptions, and conduct the required correspondence with the British Institution.

Nominations.

DURING the first week in February the Secretary will send to the membership, as required by the Constitution, the necessary forms and envelopes for preparing nominations for the offices becoming vacant this year. In case of failure to receive these forms, the Secretary will, upon request, send single sets; he is not permitted to send them in quantities. The nomination forms should not be signed, but the name of the sender should be placed on the envelope. A form of proxy is also enclosed. This cannot be utilized for voting for officers, but only for any business which may be brought up at the annual meeting. Proxies should be filled in with the name of a person who is likely to attend the annual meeting. It is desirable that they should be returned, as proxies may be required to ensure a quorum. They may be enclosed with the nomination forms, and this practice is convenient and preferable.

Branch Meetings.

THE experience of several of the Branches having the largest membership has led to decided improvements in their practice. Some of them have prepared excellent schedules covering the entire season, and in these cases original papers are usually to be provided by local or visiting members. There now appears to be a better understanding regarding the use of papers which have been presented at the New York meetings, which may be abstracted and discussed if deemed advisable by the local officers or committees, in case nothing more suitable can be provided for the local meeting. Where the author can present an important paper in person, especially if accompanied by demonstrations or lantern slides, the best results are attained. One precaution should always be carefully observed. The person who presents a paper at any meeting should be a member or a person of such standing that there can be no question as to the merits of his subject or the manner in which it is treated. While the actual presentation of a paper of an inferior grade might cause no harm, the fact that it has been read at an Institute meeting may be used for advertising purposes or in some objectionable way which would cause annoyance. There should be little difficulty in making inquiries in advance, thus avoiding any such possibility. The By-laws provide that unless accepted by the Institute for publication, no reference should be made to its presentation at an Institute meeting, if published elsewhere by the author.

PREPARATIONS are being made for removing the offices of the Institute to the Engineers' Building, 33 West Thirty-ninth Street on Saturday, February 2. The library will follow on February 4, provided the shelving is ready for the placing of the books. At the proper time notice of change of address will be sent to all members. Another week will possibly be required for the delivery of new furniture and laying of carpets.

INQUIRERS for copies of papers would save time and trouble if they would first ascertain the name of the author, the exact title of the paper, where it was presented, and the approximate date. The time to do this is when they first hear of the publication. By giving as much of this information as possible, a search for the required article will be greatly facilitated. Many of the papers asked for from time to time have not been published by the INSTITUTE.

Engineering Education*

By Arthur J. Rowland.

I am going to ask your attention to some thoughts of mine which seem to centre pretty well about the topic—The proper scope of engineering education: in particular, the proper scope of electrical engineering education. All education, or certainly such branches as are at all familiar to any of us here present, may be broadly divided into two sorts; general education and professional education.

General education includes two sorts of subjects, these are:

(*a*) Those which are studies for the requirements of every day life, but without any especial object in view. Included in this class will be subjects like arithmetic, reading, writing.

(*b*) Those which are studied for the sake of the culture which they give to the persons who pursue them. In this class belong literature, history, language, and related subjects; in some cases mathematics and science are culture subjects.

Professional education is distinctly different. It includes subjects, a knowledge of which is essential to the carrying out of the duties of a given profession. It includes not only subjects which present the practice of a profession, but those which set forth the principles and theory underlying the practice; those which form the foundation stones upon which the professional career is to be built.

Engineering education is of this latter sort. Part of it is obtained in technical schools, or universities. Another part can only be obtained in that school everyone of us still attends—the school of experience.

Narrowing our thought to include for the most part the professional knowledge which is found in books, and which is best obtained under instruction, it needs no demonstration that in the earlier part there must be included such fundamental subjects as mathematics, physics, chemistry, etc. That the various branches known as engineering subjects must be included, goes without saying; a considerable amount of time being spent upon expositions of *why* things in nature are as they are—the laws of the subject—the theory if you choose, always illuminating this carefully with practice. And the scope must be such that in later life supplementary and advanced study *alone* is necessary to give an engineer the proper grasp of a subject he needs in order to solve any problems which present themselves. The work done on subjects which are the fundamentals of engineering knowledge must be so well and completely done that the superstructure, no matter just what its character, can be reared successfully without need of consideration for the foundations. They must have been laid strong and wide and secure.

And just here let me call attention to the fact that I am speaking of an education for an engineer. I therefore have no thought of trade school courses, elementary technical courses, and the like; which, if given with honesty of purpose, are only intended to fit men for the less important positions in the wide field of engineering applications, (those in manufacturing, operating, and the like).

What I have so far said would probably be said by anyone connected with engineering education. But how far shall the education go? How comprehensive shall it be made? There is no school where engineering is taught but it would be easy to lengthen the course and make it extend over more time. There is no one who comes to the end of his course, but he feels, if he understands at all what engineering is, that his professional education has not more than just begun.

Before a man starts on an engineering education, he has decided what he proposes to make of his life; not only has he considered what his inclinations and abilities are, but what sort of career he may expect. Hence the expenditure of time and money upon a course of study (in many cases this means not only a direct expenditure of money, but a sacrifice of earning capacity as well), is an investment which is made, as is any investment in any business venture, with a view to the returns which are to be expected.

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*Presented at a meeting of the Philadelphia Branch of the American Institute of Electrical Engineers, December 10, 1906, in the new engineering building of the University of Pennsylvania.

Now depending upon his age, his position in life, and his earning capacity, there is a time for each man when any gain he is making in education is over-balanced by the cost of it to him; and so the time has come when he ought to stop paying tuition, and under an entirely different environment, partly in the school of experience and partly by reading and study alone or in some special way, continue his education.

In making this statement it will be clear that certain things have not been taken into account. A student cannot stop a course at some particular point of its length, for example, three quarters the way through and realize three quarters of the benefit of what the course had in it for him. Nor can he select such subjects as he pleases to put into the three quarters that he takes, for reasons obvious to anyone who has had experience in educational matters. I believe that a man who enters a given course of study ought by all means to follow it through and graduate from it. But in order to give some support to the opinions I have expressed, I want to ask you to listen to some ideas in reference to the arrangement of an engineering course.

I do not believe there is one standard plan, requiring a fixed number of years to accomplish the amount of education which properly belongs in an engineering course. I have stated earlier in this paper that it is vitally important to have the foundations properly laid. But it is possible, on the other hand, so to arrange things in a long course, that at the end of any given period, a definite kind and scope of engineering study has been accomplished. I mean to contrast this with the plan, too often found in engineering, as in other professional courses, where everything is planned to be preparatory to, or to lead up to, the final year of work.

By a suitable arrangement of subjects of instruction, such as I have suggested, even the man who is stopped in a course because of inadequate mental endowment to pursue it further, leaves the institution where he has been under instruction with an equipment of engineering knowledge complete in itself, so far as it goes, even if he never attempt on his own account to extend it further. Somehow, in my experience, I find many men who have fine engineering qualities—particularly in the direction of being able to do things and do them well—who have tremendous difficulty in mastering higher mathematics and pure science; subjects usually placed early in their courses. Failure to pass them often forces them out before real engineering education has been begun.

Hence, I am in favor of an arrangement of subjects which does not follow "standard" lines. Some subjects must take precedence of others, but physics and trigonometry can be studied together; physics need not be completed before engineering subjects are begun; analytical geometry can be rather better taught with calculus than preceding it; mechanics of materials and alternating currents can be taught side by side with the study of calculus; and all these things can be done without the sacrifice of any valuable principles in any of the subjects. In fact, the close association of subjects like those just mentioned is of great advantage. Students are thus enabled to see the application of what seems like an abstract principle even while studying it. How many of us would have been delighted to know, when we were being introduced to such symbolism as $\frac{dx}{dy}$ or $\int_a^b ydx$ that these things embodied ideas of vital consequence in many lines of engineering. How much our interest would have been awakened in subjects we thought were abstract and uninteresting, but which we had to wade through because they were in the course, if their intimate relation to other subjects in which we *had* a lively interest could at the time have been made plain to us. According to the method I am setting forth, even if at times mathematical knowledge lags behind the requirement of another subject, it seems to me that in all engineering work a physical conception of phenomena is far more important than a mathematical conception. Thus in an alternating current circuit it is much better to know that the electromotive force of inductance lags behind the current there flowing by one-quarter period, as a simple and direct consequence of Lenz' law of electromagnetic induction, than to base this wholly on the differentiation with respect to time of the instantaneous value of the current expressed as a sine curve in a mathematical equation. The first method makes it real; helps it to live in a student's thought and memory. The other invariably seems abstract. Both together are properly supplementary and it is best, of course, to understand both.

Once more, a few words in reference to the subjects which are properly included in an engineering course—one of professional study. Culture work is not properly included in it. The study of foreign languages is wholly a culture study. Some foreign language used to be thought necessary as a means of looking up engineering information. There never was a time when there was as little need for a knowledge of foreign language with this in view, as at the present time. No one, even if he devotes a large part of his time to it, can keep up with the literature and periodical information in his *own* language; not even in a single narrow line of engineering. English language and literature study is being eliminated from many college courses in engineering; a sort of culture work far more important, it seems to me, than the other. But there is another sort of culture study harder to eliminate from engineering courses. The subjects of mathematics, chemistry, physics, and even drawing, can be and often are taught as culture subjects. The higher mathematics, if taught by a mathematician, becomes largely a sort of mental gymnastics; valuable no doubt for mental culture, but to most students a subject apart from, and having little connection with, the engineering studies in which it is made use of. In the hands of an engineer, mathematics is a means to an end; a tool to be used as a means of digging out solutions to practical problems. To a mathematician, mathematics is not practical and should not be considered except as an abstract subject of knowledge. Physics, whose relation to engineering is so vital that the man who cannot compass its principles is unlikely to gain any real understanding of engineering problems, can easily be made a pure science subject, so pure that its connection with engineering becomes almost, if not wholly, lost. Drawing may partake so much of art, that those vital purposes on account of which it is made a necessary part of an engineering education would never be revealed.

And yet there is a culture which, it seems to me, ought to be made an important part of an engineering course. Engineering has a history and a literature of its own to which every student should gradually, in the course of his study, be introduced, and with which he ought to come to feel very well acquainted. There are many lives of engineers which are as much an inspiration to high ideals, to honest working, to benefit their fellow men, as any to be found in literature. There are many achievements in engineering, a knowledge of which is as much a matter of culture as anything to be learned from a history of nations, especially if the latter includes the study of conquest and of political intrigue.

Last, of all, a word in reference to the scope of electrical engineering education. Electrical engineering education is an outgrowth from physics and mechanical engineering. All of us can remember how, fifteen years ago, it was often said that electrical engineering was nine-tenths mechanical engineering and one tenth Ohm's law. That time has long passed. An electrical engineering course must indeed include mechanical engineering subjects as surely as does a civil engineering course; but it is not hard to find courses where thermodynamics and steam engine occupy as important a place as electrical subjects. There are a large number of positions in electrical engineering, probably a majority of places, where no knowledge of steam is required at all; where the knowledge of thermodynamics and heat in physics and in electrical study more than covers all requirements. I believe thoroughly in a strictly and distinctively electrical course for electrial engineers. And above all, I believe in having all the subjects of a course in engineering taught by engineers who are working together to one common end.

A Summer in the General Electric Test*

To start at the beginning of things, it was one morning in June this last summer when I first formally reported at the General Electric works in Schenectady. First impressions were not as marked in my case as in most cases, because two weeks before I had visited the works while on the annual inspection trip of the senior electrics.

In the waiting room I met several of the college graduates about to start in. After having been presented to the electrical superintendent, Mr. Rohrer, we were sent down to one of his assistants for final instructions. As we were seated in the last mentioned office, awaiting our turn, the thing which occupied our attention most was a Red Cross case, which suggested accidents to come. This thought was more forcibly brought to mind by the assistant asking, among other things, our religion. I do not know the true reason for asking that question, but the only one that has been suggested is, to know what kind of a divine to call in case of serious accident.

The questions through with, we were then assigned to places in the machine shops. This was rather unexpected, for hitherto college graduates had been placed in the testing department immediately. Some of the men were placed on purely mechanical work, such as helping on large boring-mills, on drill-presses, lathes, etc. Others were placed in the commutator department, with the winders of induction motors and also direct-current motors, with assemblers of regulators, transformers, motors, etc. I chanced to be among those assigned to induction motor assembling.

As I have said, we were the first set of college graduates to be placed in the machine shops, and undoubtedly many changes in methods of placing and shifting men have since been inaugurated which will serve to give the man starting in a more comprehensive idea of the manufacture of a machine from start to finish. However, as it was, most of the men heartily endorsed this scheme of a month or two of preliminary machine-shop work.

In my own case, the work was interesting, involving as it did the assembling of field-spiders, armatures, shields, bearings, oil-rings, oil-gauges, etc., of induction motors ranging from five horse power to five hundred horse power; the lining up of motors and outboard bearings on bases; and, incidentally, about a week of assembling bases for small motors, which was mostly a case of chipping castings.

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*A paper read by Andrew W. Farnsworth at a meeting of the Worcester Polytechnic Institute Branch of the A.I.E.E., November 12, 1906.

Not only was the work interesting, but I appreciated the opportunity of conversing with the men as fellow workmen. On the whole I found them to be more intelligent than similar workmen in the New England States. They were well organized and seemed to have the prices on piece-work, which is the common basis of payment, arranged so that no man need make less than union wages. Certainly, I had little difficulty in earning union wages when on piece-work. Here, too, was seen a source of the socialistic movement now gaining so much headway the country over. Without exception, the men seemed to look on it as some kind of movement which would give them as much money, yearly, as their superiors. Their socialism appears to be solely a monetary one.

At the end of five weeks I was transferred to the induction motor test. As the induction motor is one of the most perfect of electrical machines, and one of the easiest to test, little can be said about the electrical end of this test.

Here again I found a Red Cross case, and learned that the provisions for caring for the injured are most complete. The head of the test is in every case skilled in giving first aid to the injured, but for final care and for serious injury there is a hospital located centrally to the whole works. A trained nurse is on duty at all times and the best of care is rendered free of charge.

And so as the weeks went on, many things came to my notice which showed the thought which the men in charge have given to the comfort and safety of the workmen. As for the works, themselves, a detailed description of them would require volumes, and is far beyond the scope of this article.

A few words must be said as regards the test men themselves. All types of men were encountered, men from every part of this country and from all countries of the globe. There were men with means and men without means. I have in mind two men: one, an Englishman of rank, who, when asked where he was staying, replied:

"At the Mohawk Hotel."

"But don't you find that a bit expensive," asked the other.

"Oh, only fifteen dollars a week and a few extras," was the reply.

The other man said he was going to put a dollar a week in the bank. They were both receiving $8.40 a week.

And so there were extremes in many ways, but one could not help thinking that he was meeting men who will in the near future play a prominent part in the electrical world.

There is another side to the test life, and that is the part spent away from the works. The city of Schenectady is not an inviting one, as a person with the income of a test man sees it. Wherever he turns to seek room and board, he comes in contact with the laborer and his struggle. All of the family that can possibly be spared are working either for the General Electric Company or for the American Locomotive Company. The wife and younger ones stay at home and plan for the boarders, and roomers, if by chance there is an extra room. Supplies are high, as is also rent, and accommodations within walking distance of the works are poor.

It was a genuine pleasure after a week of toil to walk to the other part of the city and see the Carnegie Library, the Union College Buildings (reminders of happier days), and the residences of the officers of the company. Then, too, there were numerous chances to see the neighboring country, by means of trolley, small launches on the famous Erie Canal, and various excursions on the steam roads. All in all, I consider it a summer well spent, and rich in experiences that will be lasting in their benefits.

A Summer Experience with the Westinghouse Electric and Mfg. Company*

In looking for summer work the question of wages is more likely to appeal to a student who has nearly completed his college course than the question of experience, but with the present trend of electrical development it is exceedingly difficult for a man without experience to obtain more than enough to cover his living expenses, and a junior finds himself in just these circumstances. It is most beneficial for the student who has just completed three years of theory, to obtain some practical points in the application or construction of actual apparatus, and the methods most common in practice.

Of the large manufacturers of electrical machinery offering opportunities for summer practice to students, the General Electric Co and Westinghouse Electric and Mfg. Co. are most prominent. Although the wages which these companies pay are exceedingly small and not sufficient to cover the expenses of those who come from a distance, yet the course of practice which they offer is profitable enough to offset any deficiency in wages. The method of employment with the Westinghouse Co. is so carried on that in a little less than two years a student has covered all of the important departments of the manufacturing side of the electrical work, and has besides spent some time in the engineering offices.

When beginning employment with the company, the student is placed in some one department of the shops and works under the direction of a journeyman, actually doing the work in process in that department. He is kept in this department long enough to become familiar with the methods and constructional points which come before him, and is then changed to another department. Opportunities are given him for inspection of the work throughout the shops, so that many " pointers " may be obtained outside of the department in which he is working.

Briefly looking over the experiences of a junior student the past summer, at the Pittsburg works of the Westinghouse Electric and Mfg. Co., you will find him first employed in the coil department, which is one of the largest in the shops. Eight weeks were spent in this department winding and testing transformer coils, winding and insulating armature coils and field coils, and preparing insulation for the many purposes for which it is used throughout the shops. Having spent enough time in this department to obtain a fair idea of the work carried on there, a transfer is given him to the railway motor department.

Here we find him placed with a wiring-crew, wiring up some of all the types then under construction. He is next placed with assemblers and worked with them for some time, and then given motors to assemble by himself. This latter work gives him more experience than any other that he does during the summer, as it places him upon his own resources, and gives him a chance to study thoroughly the construction of the motor which he assembles.

It might well be added that the experience one obtains not only in the Westinghouse shops but also in visiting the many large manufacturing industries of the city of Pittsburg is well worth while.

Even in the daily walks of business there is frequent temptation to obscure the truth. But the man who passes his life in contests with nature is not apt to be a sophist. The engineer can have no object in concealing the truth or in misusing it. His work is a material fact; it is not an impression upon the minds of other men. No ingenuity of argument, no power of rhetoric will save one ounce of coal per horse-power-hour. We all know in some vague and abstract way that we must yoke our wagon to a star, but the engineer must do it.—*Henry G. Prout.*

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*A paper read by P. C. Smith at a meeting of the Worcester Polytechnic Institute branch of the A.I.E.E., November 12, 1906.

Summer Experience*

The idea of entering telephone work was first presented to me by the representatives of different telephone companies, who came to the Institute last spring for the purpose of recruiting students. The American Telephone and Telegraph Company seemed to offer the best proposition, and I became one of several Institute men to enter their employ. It was agreeably arranged that we were to work together in groups of two.

Early in June, Mr. Quimby and I reported at the company's office in Derby, Conn., and began work as equipment men under the direction of an inspector. Our first job was the installation of a test-station at a junction of two of the New York-Boston lines. The apparatus to be installed consisted of bridle-cables, lightning-arresters, heat-coils, and the test-board with its cross-connecting rack. The general arrangement of the equipment was determined by blue-prints, while minor details were left to the judgment of the inspector. Thorough tests were applied to each part of the apparatus during its assembly, and the station was tested as a whole before it was finally connected to the lines.

As the inspector in charge of this work was a cable-man as well, we were given considerable experience in the laying of submarine cables, in the making of splices and pot-heads, and in the wiring of cable-boxes. In this regard, some account of the laying of a 22-pair, lead-sheathed, armored cable may be of interest as bringing out some of the problems which the telephone engineer should be prepared to meet.

The cable referred to now carries the Midland line under the Connecticut River at Bissel's Ferry, Connecticut. The cable was about 1600 ft. long and, with the reel, weighed about seven tons. It required a strong truck, brought from Hartford, to convey such a heavy weight to the river bank. Here it was unloaded and rolled upon the ferry-scow over a plank roadway supported by substantial blockings of old railroad ties. A seven-strand guy-wire was stretched across the river in line with the terminal-poles, and the scow fastened to this temporary cable by a pair of running-blocks. All the preparations being complete, the actual laying of the cable required little more than an hour.

After two months of such work, I was employed for the remainder of the summer in the manager's office at Derby. The work assigned me was the preparation of drawings and estimates for proposed test-stations, but a fair proportion of my time was spent in locating and repairing various troubles in the wiring and boards of the switching station then in operation at the office.

From this imperfect account, it will be seen that a student taking up summer work with the American Telephone and Telegraph is given a variety of tasks, furnishing valuable experience, whether or not he intends to enter the telephone business.

Local Organizations

Local secretaries are invited to coöperate with the editorial staff, by preparing for publication in the PROCEEDINGS a suitable synopsis of each Branch meeting; this is not to supersede the formal official report for which printed forms are furnished. Both official form and synopsis should reach the Secretary on or before the sixth day of the month following the meeting.

UNIVERSITY OF ARKANSAS.

PROGRAM FOR 1907.

January 15, A.I.E.E. paper by Mr. C. R. Rhodes. "Boiler Explosions," by Professor N. B. Wilson.

February 5, A.I.E.E. paper by Mr. W. S. Bayley. "Electroplating," by Professor L. S. Olney.

February 19, A.I.E.E. paper by Mr. V. A. Harding. Original paper by Mr. R. M. Edwards.

March 5, A.I.E.E. paper by Mr. S.

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*A paper read by Joseph T. Butterfield, at a meeting of the Worcester Polytechnic Institute Branch of the A.I.E.E., November 12, 1906.

B. Graham. "Measurement of the Speed of Electricity," by Professor H. Schapper.

March 19, A.I.E.E. paper by Mr. K. A. Reed. "Winter Tests on Electric Meters," by Mr. M. F. Thompson. Original paper, by Mr. J. R. Belknap.

April 2, A.I.E.E. paper by Mr .O. E. Hicks. "The Arrhenins' Theory of Electrolytic Dissociation," by Professor C. G. Carroll.

April 16, A.I.E.E. paper by Mr. G. C. Baker. "The Electrification of Steam Railways," by Professor W. N. Gladson.

May 7, A.I.E.E. paper by Mr. E. H. Dickson. Original paper by Mr. E. B. Critzer.

May 21, A.I.E.E. paper by Mr. W. D. Berry. Original paper by Mr. W. B. Stelzner. Original paper by Mr. V. A. Harding.

BALTIMORE.

At a meeting of this Branch held December 14, 1906, there was adopted a resolution continuing the present officers and executive committee in office to June 1907. The annual election of officers, under this arrangement, will take place at the last meeting prior to the summer recess, in order that the new organization may start with the opening of the Branch work in the fall, instead of as at present when the change of officers occurs, in the middle of the year.

Mr. W. I. Slichter, of the engineering staff of the General Electric Company, read a paper on a "Comparison of Alternating Current and Direct Current for Electric Traction." The paper was one of much interest and aroused a lively discussion. Those participating in the discussion were Dr. Whitehead, Messrs. Shepard, Adams, Thomas, Keilholtz, Foster, Edwards, Slichter, and Hewes.

At the meeting of the Baltimore Branch, held in the Physical Laboratory, Johns Hopkins University, January 11, 1907, Mr. Charles E. Phelps, Jr., chief engineer of the Electrical Commission of Baltimore City, read a paper on "Underground Transmission and Distribution of Electrical Energy." The author's introduction will indicate the scope of the paper:

"It must first be appreciated that the title of this paper introduces a broader field in electrical operations than can be fully covered in a single evening, but that the subject has purposely been made broad in order that a varied assortment of important details may be considered, affecting the successful operation of underground transmission and distribution of electricity."

The paper then followed the history of conduit construction and underground cable development, pointing out the relative influence of legislation to overcome the nuisance of overhead wires, and the desire of station managers to secure a more permanent and stable system of distribution; finally, the necessity brought about by the advent of 11,000 and 13,000-volt transmissions in cities.

The conduit system was treated at some length and the elements determining the design of a system were analyzed. The importance of manholes of suitable size and form was emphasized. The distinction between trunk and distributing conduits was defined; the problem of guarding against the accumulation of gas and consequent explosion was discussed. The various methods of reaching the customer from the conduit were described.

Samples of many classes of cable were displayed, and the manner of installation shown. The necessity of careful arrangement of cables in manholes and their protection was dwelt upon.

The relations of the purchaser and the cable manufacturer and contractor were discussed. Cable appurtenances, such as feeder and main junction-boxes, service and connection-boxes of various types were described and shown.

The method of guarding against

the electrolysis of the lead cable sheaths was gone into at length.

The discussion, after the reading of the paper, brought out the fact that the high percentage of defects in 1903 was due to the aggravated condition of the street railway return system, which was corrected in the latter part of the year; and in 1904 and 1905, due to the great amount of work attending the changes of streets and re-location of conduits following the fire of February 1904.

The paper was illustrated with lantern slides, showing overhead wire conditions before and after the wires were placed underground in Baltimore. Details of conduit and manhole construction, including some special devices for crossing the several streets within the city, cables and cable appurtenances.

[An abstract of the "faults" commented on in this paper will be printed in a future issue of the PROCEEDINGS. —EDITOR].

BOSTON.

A meeting of the Boston Branch of the American Institute of Electrical Engineers was held in the Lowell Building, Massachusetts Institute of Technology, on Wednesday evening, December 19, Professor Clifford presiding. One hundred and fifty-eight members and visitors were present.

The paper of the evening was given by Walter V. Turner, Mechanical Engineer of the Westinghouse Air Brake Company, on "The Development of the Air Brake for Steam and Electric Traction Service." Mr. Turner traced the development of the air brake from its earliest form to the most improved electropneumatic type in use at the present time, showing it to be one of the most important features of heavy electric traction, and that its development has kept pace with the increase in weight and speed of equipment. During the discussion which followed the reading of the paper, Mr. Turner made the following extemporaneous remarks:

When a person gets into the air-brake subject, dealing with it from both the steam and electric points of view, he finds it a large proposition; in fact, the electric end itself covers too much ground for one evening. I have quite a long paper and will have to cut out some of it. There is none of it from my point of view that I can dispense with without leaving out considerable that is of interest. Perhaps next to Christianity, the press, and the locomotive, the air brake has done more to develop America than any other one thing. I know that most of you will look upon that as a tall statement, as we sometimes say, but the intercourse between people depends absolutely upon the ability to control the medium of interchange. Very few here, perhaps, have studied the subject sufficiently to realize that the brake under a single car is much more powerful than the locomotive that pulls the train. I am speaking now of steam roads. Few realize that it takes a locomotive five minutes, perhaps ten minutes and a distance of many miles, six or seven miles, before it attains a speed of sixty miles an hour. What would you think if it took a brake that length of time and distance to stop a train? What it takes a locomotive ten minutes and perhaps six miles to accomplish, the brake must do in twenty seconds. We are able to stop a train to-day from a speed of sixty miles per hour in twenty seconds of time. To build a locomotive that would accelerate a train in the time and distance that the brake stops it, would be impossible; the locomotive itself would have to be twice as heavy as the train in order to accelerate the train as rapidly as the brake retards it. That is not allowing anything at all for the power required to move the engine, so that it resolves itself into a physical impossibility, so far as the steam locomotive is concerned.

What an electric locomotive will do is another proposition. But we have every reason to believe that the electric locomotive will be able to accelerate a train and get it going at sixty miles per hour in certainly not more than a minute and a half, and probably not more than one minute's time. That means that the brake is going to be more important in the future than it has been in the past. In proportion as you accelerate, you must perforce be prepared to decelerate. Your ability to accelerate or even to run at high speeds must be measured by your ability to decelerate. I merely mention these things to show you the great importance of the air brake. The subject is branching out. It has become a problem for the electrical engineer to consider, and a very serious one, as it was with steam engineers in the years gone by; and it is for that reason that I take great pleasure in meeting so many here to-night and to show you the problems involved in building brakes for the service of to-day, and I hope I may be able to make clear to you the advancement or development of the air brake since electric traction became so prominent.

I may say that one of the causes of the development of the air brake has been the electric development. We tried to adapt the regular steam-road brake to electric service, but with very indifferent success. We quickly found that we were dealing with an altogether different set of factors, and for that reason many things were needed. A few years ago we started out to see what could be done in the development of the electric brake, and found it had about as many possibilities to it as the electric science itself.

With the automatic brake on connected cars, irrespective of whether the car has an air compressor on it or not, a pipe runs through the train which is charged with air and is in communication with a triple-valve under the car. Consequently, if anything ruptures the pipe, the auxiliary reservoir acts upon the piston of the triple-valve, which moves it over, carrying with it the slide-valve, which in turn registers in ports communicating with the atmosphere, and the pressure of this auxiliary reservoir applies the brake. That is all there is to the automatic brake as far as its automatic feature is concerned.

I want to call attention to the essential difference between the straight air and automatic brakes. No doubt you are all familiar with that part of it, but to make sure that we all understand it from the same point of view, I will say that with straight air the one chief defect was that if you should couple more than two cars together in operation, and those cars should break apart, which is by no means uncommon, the brake would be entirely lost on both cars. It would release if it was applied, and it could not be applied if it released, so that it becomes obvious that as a brake, the straight air was not satisfactory for more than one vehicle, and, in my opinion, not very satisfactory for that.

I might mention that in all traction service there are two pieces of hose employed, one of them being the brake-pipe in operation all the time and in communication with the triple-valve. The other one runs through the train so that the air from the different compressors may be brought up to the car used as an operating car, and assists in replenishing the system and also in releasing the brakes.

The regular monthly meeting of the Boston Branch of the American Institute of Electrical Engineers was held on Wednesday evening, January 9th, in the Lowell Building of the Massachusetts Institute of Technology, Professor Clifford presiding. Dr. Charles E. Lucke, consulting engineer of the De La Vergne Machine Company, gave a paper on "The Regulation of Gas Engines," a subject of considerable importance at the present time in view of the increasing use of such engines in electric lighting plants. Dr. Lucke discussed the development of regulation as applied to steam engines, giving a critical resume of the most important published articles treating of the subject, many of which were originally printed in the TRANSACTIONS of the American Institute of Electrical Engineers. This was followed by a comparison of the corresponding problems as they occur in gas-engine regulation.

Dr. Lucke particularly emphasized the importance of studying the load conditions actually occurring in commercial use rather than attempting a solution for a fictitious absolutely constant load, considered equal to its mean value. He showed that the variations in the load are just as important in their effect on regulation as the variations in speed due to the engine itself, and that a mechanical governor can never give perfect regulation until some modification is developed which will prevent cyclic interference. The study of the relation of the resultant of the effort and load curves on the speed curve was shown to be a very powerful method of attack, and in Dr. Lucke's opinion the one best worth attention at the present time.

The paper was followed by an animated discussion contributed to by various representatives of the turbine and automobile interests. The attendance was one-hundred and seventy-five.

At the next meeting of the Branch on February 20, Farley Osgood, general manager of the New Milford Power Plant, will give a paper on power-plant operation.

CHICAGO.

At a recent meeting of this Branch the following officers were elected to serve for the Institute year 1906-7: P. B. Woodworth, Chairman; H. R. King, Secretary; P. B. Woodworth, L. A. Ferguson, K. B. Miller, F. E. Woodmansee, J. G. Wray, H. R. King, Executive Committee.

CINCINNATI.

A meeting of this Branch was held on Wednesday, December 12, at the Hotel Havlin. The meeting was preceded by a banquet at which forty members and guests were present. The dinner was followed by a paper on "Steam Turbine Losses," presented by Mr. Hans Holzwarth, chief engineer of the Hooven-Owens-Rentschler Co. Ten additional members were present while the paper was read. The next meeting will be held about the middle of January, the subject being "Wireless Telegraphy," by Professor J. E. Ives of the Cincinnati University.

CORNELL UNIVERSITY.

As was briefly noted in the December PROCEEDINGS, Mr. G. A. Wardlaw of the Institute, on December 7 read an original paper on "Literary Engineering." Although this meeting occurred on the same day as the tragic fire at the Chi Psi fraternity house, one hundred and fifteen members and visitors were present to listen to the lecture. The evening was also one of the stormiest of the winter. It was agreed that the topic presented by Mr. Wardlaw was a most important one, and his method of presenting the subject with numerous illustrations was very effective. The entertainment committee had planned a reception to Mr. Wardlaw, to follow the meeting, but on account of the sadness pervading the city this was abandoned.

Two meetings of the Branch were held in January, one on the 4th and the other on the 17th. The attendance at the first meeting was light, as it occurred just at the close of the Christmas vacation. However, the paper by Mr. R. P. Jackson aroused considerable interest and it was discussed by a number of local members who had information to contribute. Mr. R. Rankin contributed materially to the discussion. Mr. S. R. Dodds of the local Branch had attended the New York meeting and gave his impression of the same.

The meeting of January 17, at which Dr. C. H. Sharp presented his interesting paper on recent types of incandescent lamps, was attended by one hundred and ninety members and visitors. Dr. Sharp gave a demonstration of the relative performance of different types of lamps, including the new series General Electric lamp which was not shown at New York. After the lecture an informal reception was tendered Dr. Sharp, and music and refreshments contributed to the enjoyment of the evening. Dr. Sharp's lecture aroused great interest, as was manifested by the attendance, which was noteworthy in view of a number of counter attractions occurring on the same evening.

The social side of the local Branch work is receiving more attention this year than last, with excellent results. The expenses of the entertainment are borne by a small local assessment, and the burden of entertainment is distributed by appointing different entertainment committees for the several meetings. There are now one hundred and three members of the Branch and the number is increasing steadily.

UNIVERSITY OF ILLINOIS.

Fifty-six members and students attended a meeting of this Branch, held in the Physics Lecture Room of the University of Illinois, on January 9, 1907. Professor Charles T. Knipp presented an abstract of the paper on the "Helium Lamp" read before a recent meeting of the American Association for the Advancement of Science, by Professor Herschel C. Parker of Columbia University. The Institute paper entitled "Recent Investigations of Lightning Protective Apparatus" was abstracted by F. G. Wilson, and then discussed by Messrs. M. K. Akers and Morgan Brooks.

Professor Knipp also presented a paper entitled "Temperature in the Mercury Arc." This paper was read by Professor Knipp at the joint meeting of the American Physical Society, and the American Association for the Advancement of Science. The paper was illustrated with slides, and after the meeting the apparatus was demonstrated in Professor Knipp's private laboratory.

LEHIGH UNIVERSITY.

The Electrical Engineering Society and the Institute Branch at Lehigh University have already held four of the eight interesting meetings planned for the season 1906-1907. The date on which each meeting was held, and the program of the evening, is shown by the following:

October 12—Opening Night

Opening Address, A. W. Lawson.

McCall Ferry Power Co., John W. Beyer.

Three-rail System, J. I. Porter.

Address, Professor Wm. Esty.

November 12

Electrolytic Refining of Copper, G. K. Reel.

Interpole Motor, A. B. Grubmeyer.

Some Relations of the Engineer to Finance, Clarence E. Clewell.

December 11

Geneva, Waterloo, Seneca Falls, and Cayuga Lake Power Co., R. J. Green.

Development of Water Power on the Pacific Slope, E. S. Foster.

Notes on Recent Developments in Electric Manufacture, Professor Wm. Esty.

January 8

Some Points about the Westport Generating Station, Wm. De Baufre.

Uses of Electricity in Metallurgy, G. K. Herzog.

The program for the rest of the season is as follows:

Special speakers: W. S. Murray, L. U. '95, electrical engineer, New York, New Haven and Hartford Railroad; Frank W. Glading, L. U. '94, electrical engineer, Westinghouse Electric and Manufacturing Company; F. N. Hibbits, Superintendent Motive Power, Lehigh Valley Railroad; C. F. Scott, consulting electrical engineer, Westinghouse Electric and Manufacturing Company.

February 11

Electrical Equipment of the Saint Clair Coal Company, A. W. Lawson.

Automatic Devices in a Modern Power Station, E. L. Wilson.

Electric Locomotives, S. S. Seyfert.

March 12

History of Electrical Science, M. T. Saldana.

Baltimore and Ohio Electric System, F. T. Leilich.

The Electric Arc, Professor W. S. Franklin.

April 9

Development of Electrical Plants in Cuba, A. A. Goytisolo.

Homopolar Dynamos, Wm. W. Crawford.

Wireless Telegraphy, E. E. Ross.

May 21—Electrical Blowout

Program to be issued later.

Officers of the Branch, 1906-1907:

Wm. Esty,, Advisor; Alfred W. Lawson, President; George M. Baker, Vice-president; Manuel T. Saldana, Secretary; George K. Herzog, Treasurer.

UNIVERSITY OF MICHIGAN.

At a recent meeting of this Branch, the following officers were elected to serve during the Institute year, 1906-7:

Kenneth Barry, President; B. Nagelvoort, Vice-president; W. K. Rhodes, Recording Secretary; C. J. Whipple, Corresponding Secretary and Treasurer.

MINNESOTA.

At a meeting of this Branch, held December 15, 1906, the Secretary read an invitation to the Branch to visit the steam power station of the Twin City Rapid Transit Company, on December 29. Under the general subject of " New Types of Lamps, Arc and Incandescent," Messrs. A. E. Pierce and H. J. Gille, abstracted the recent Institute papers read at New York by Messrs. Steinmetz and Sharp. A. J. Marshall outlined the adaptability of various illuminants to various classes of work, and a number of the new types of lamps were shown in operation.

On the afternoon of December 29, 1906, the Minnesota Branch was the guest of the Twin City Rapid Transit Company at the 2400-kw. steam power station at Minneapolis. The entire plant was thrown open to inspection. An illustrated description of the station, giving the principal dimensions and details regarding equipment, had been printed for the occasion, and was presented to the visitors. Messrs. E. H. Scofield, J. C. Vincent, W. D. Whitney, and Barry Dibble, acted for the company in entertaining the guests. About fifty members and their friends were present.

[The description referred to above will be printed in a future issue of the PROCEEDINGS.—EDITOR].

UNIVERSITY OF MISSOURI.

At a meeting of this Branch, held January 4, 1907, the Institute papers on " New Types of Incandescent Lamps" were presented and discussed.

PHILADELPHIA.

On January 15, 1907, seventy members and guests of this Branch attended a meeting at the Engineers' Club. W. A. Cohen presented a paper entitled " The Magnetite Arc Lamp," showing the lamp in operation. Dr. Clayton H. Sharp presented his paper entitled "New Types of Incandescent Lamps." Dr. Sharp illustrated his paper with lantern slides, and showed the lamps in practical operation. The following is a program of the meetings to be held by this Branch during the remainder of the Institute year, 1906-7:

January 14, Illumination.

February 11, Train Signaling for Electric Roads. A Bond-testing Car.

March 11, Marine Applications of Electricity.

April 8, Electrical Measurements.

May 13, A New Method for Lighting Steam Railway Trains Electrically.

June 10, Annual Meeting.

PITTSBURG.

On December 11, 1906, seventy-four members and guests of this Branch attended a meeting at the Carnegie Technical Schools. Under the general subject of " New Incandescent Lamps," Mr. R. B. Parker abstracted a paper read by Mr. F. W. Willcox before the Michigan Electric Association at Grand Rapids, October 10, 1906.

Mr. C. E. Stevens abstracted Mr. C. P. Steinmetz's paper on "The Transformation of Electric Power into Light."

Owing to bad weather, the attendance at the meeting on January 14, 1907, was less than usual; but the discussion was animated and considerable material presented that will be of value. Quite a number of prominent engineers were in attendance, and those taking part in the discussion were Messrs. P. M. Lincoln, S. P. Grace, K. C. Randall, S. M. Kintner, and R. P. Jackson.

The good effects of the Branch dinner on December 15 were reflected by the application for a number of membership blanks.

PITTSFIELD.

At a meeting of this Branch held at the Berkshire Auto Club, December 15, 1906, it was voted that the Chairman appoint two other members to act with him as a committee on the proposed revision of the A.I.E.E. Constitution. Messrs. Gilbert Wright, C. F. Adams, and H. L. Smith constitute this committee. The following papers were then abstracted and discussed:

"Repulsion and Induction Motors," abstracted by Mr. H. L. Barnholdt.

"Comments on Present Underground Cable Practice," abstracted by Mr. C. M. James.

Another meeting of this Branch was held January 3, 1907. Mr. C. T. Wilkinson read a very interesting original paper entitled: "Illustrated Lecture on the 1906 European Trip of the A.I.E.E. with Special Reference to High-voltage, Direct-current Transmission." Mr. H. H. Barnes, Jr., resigned from his position on the Executive Committee because of his leaving town. Mr. H. L. Smith was elected to fill the vacancy.

PURDUE UNIVERSITY.

Two meetings have recently been held by this Branch, on December 4 and 18, 1906, respectively. At the first meeting the general subject discussed was "Recent Electric Railway Development." At the second meeting, Messrs. S. E. Brown, W. S. Small, and A. F. McKee presented papers on the general subject of "The Apprenticeship Course from the Student Standpoint."

ST. LOUIS.

A meeting of this Branch was held December 12, 1906. The meeting took the form of a dinner at Lippe's restaurant, thirty-two members and visitors being present. At the conclusion of the dinner, the meeting was called to order by Chairman A. H. Timmerman, who introduced Mr. Frank Gaiennie as the speaker of the evening. Mr. Gaiennie read a paper describing the principal features of the new central exchange of the Kinloch Telephone Company.

At the conclusion of the paper, the meeting adjourned for an inspection of the exchange, where the party was increased by nine more members. The inspection lasted until a late hour, Mr. Gaiennie very kindly explaining the details of the entire installation.

Another meeting of the St. Louis Branch was held at the Engineers' Club, January 9, 1907.

The Committee on Membership reported that no regular meeting had as yet been held. It was voted to appoint a Committee on Papers, said committee to be charged with the duty of securing papers to be presented at the meetings.

A Nominating Committee, consisting of A. S. Langsdorf, chairman; C. R. Meston, and H. I. Finch, was elected to name a new Executive Committee.

The subject of discussion was the central exchange of the Kinloch Telephone Company, visited by the members of the Branch on the occasion of the December meeting.

The paper on "Transformation of Electric Energy into Light," by Charles P. Steinmetz, was read in full.

SCHENECTADY.

At the meeting of the Schenectady Branch, held at the High School, Saturday evening, January 5, 1907, Professor E. E. F. Creighton of Union University and the General Electric Company read in abstract and discussed a paper on "Lightning Protection," recently presented before the Institute in New York. The author of the original paper was R. P. Jackson of the Westinghouse Electric and Manufacturing Company, and it described many different lightning-arresters now in use, with interesting tests made to determine their relative efficiency.

Professor Creighton is one of the authorities in this country on the protection of electrical installations from the effects of atmospheric disturbances, and his audience listened with interest as he explained the technical details of the paper and described the different practices of the two big electrical companies.

Chairman D. B. Rushmore, who presided, pointed out the vast importance of this subject. Several immense power developments are now being held in abeyance awaiting absolute assurance that the high-voltage transmission lines necessary for their successful operation can be satisfactorily protected from lightning, and the electrification of long distance railroad lines cannot be effected until the problem is solved.

In no other branch of electrical engineering is the investigator so closely in touch with the fundamental character and inherent nature of electricity, and in no other branch does expert opinion appear to differ so widely. From either the commercial or scientific side, therefore, the invitation to the young engineer to enter this field is most enticing.

A number of men familiar with the subject participated in the discussion, among them being Messrs. Du Bois, Merriam, Goodwin, Loiseaux, Worcester, and Eichel, bringing out different phases of the practical design and operation of various types of apparatus.

At the meeting of the Schenectady Branch, American Institute of Electrical Engineers, on Saturday evening, January 12, Ernst J. Berg, of the General Electric Company, read a very instructive paper on "Some Features of Parallel Operation of Alternating-Current Generators." G. W. Cravens, who acted as chairman, made some interesting announcements regarding the work of the Branch, and introduced the speaker. The meeting was held at the High School, as usual, and over three hundred members listened attentively as the speaker explained many original formulæ for the theoretical determination of the proper method of designing and operating alternating-current machines.

Mr. Berg confined himself largely to a discussion of the formulæ involved as being more useful for the substitution of actual numerical values and illustrated by examples, but also gave in his explanations a few diagrams which facilitated the understanding of the principles. A number of the members who participated in the discussion following the reading of the paper, gave accounts of their experience in this line of work, and highly complimented Mr. Berg's investigation of the subject. Among those who spoke were A. A. Tirrill, E. B. Merriam, and C. T. Wilkinson.

At next Saturday's meeting a topical discussion will be held on "Industrial Betterment," after a few short papers on the subject have been presented. A good opportunity will be given by this subject to compete for a trip to New York to attend the meeting on "Heavy Electric Traction," to be held towards the end of the month.

SEATTLE

Fourteen members and visitors attended a meeting of this Branch on December 11, 1906. The Chairman of the committee on revision of the A.I.E.E. Constitution reported progress, and expects to make a detailed report at the next regular meeting. An original paper entitled "Electricity in U. S. Navy Yard" was then read by Mr. Cyrus A. Whipple of the Bremerton Navy Yard.

UNIVERSITY OF WISCONSIN.

Twenty-five members and visitors attended a meeting of this Branch held in the Doherty Club Rooms December 20, 1906. An original paper entitled "High-Tension Outlets" by Alvin Meyer, of Provo, Utah, was read by Professor Dugald C. Jackson. The Institute papers on "The Transformation of Electric Power into Light" and "New Types of Incandescent Lamps" were then abstracted and discussed.

[Mr. Meyer's paper will be printed in a future issue of the PROCEEDINGS. —EDITOR.]

WORCESTER POLYTECHNIC INSTITUTE.

A meeting of this Branch was held on December 10, 1906. Pres. A. P. Chapman called the meeting to order and introduced the speaker for the evening, Mr. Bruce E. Loomis of the Fire Underwriters' Bureau of New York City, who spoke on the subject, "Electrical Hazards and Fire Insurance Inspection."

Mr. Loomis began by giving a brief history of fire insurance and then confined himself to electrical appliances as fire hazards. He spoke very highly of the Fire Underwriters' Laboratory in Chicago, and explained why it had proved to be of so great value to the insurance companies. In regard to inspection, great stress was placed on the extreme caution which is necessary to exercise in guarding against the negligence of operators. Mr. Loomis spoke very favorably of the automatic-sprinkler system but placed little faith in dry-powder extinguishers.

After Mr. Loomis's address, Prof. Harold B. Smith, gave an illustrated talk on his trip through California and the Yosemite Valley.

The regular meeting of the Branch was held Monday evening, January 14, 1907, in the Lecture Room, Salisbury Laboratories. Mr. Alton D. Adams, Member of A.I.E.E., addressed the meeting on the subject, "Legislative Regulation of Rates." Mr. A. P. Chapman, President of the Branch, was the presiding officer.

Mr. Adams took a general view of his subject, giving instances of the early regulation of rates in England as far back as the seventeenth century. He discussed the conditions which have caused the recent agitation of the question in this country. He laid great stress on the doctrines of Justice Harlan, that a corporation has the right to expect a reasonable return on the valuation of its property devoted to public service. He said that the rate should not only be reasonable but that it should also be indiscriminate.

Professor H. B. Smith raised the question as to whether there might not be in some cases, especially in the sale of electrical energy, a legitimate difference of rates. Mr. Adams readily agreed with Professor Smith and said that if a company could show that it cost them more to furnish power to a small consumer than to a large one, due to the amount of energy in question, then the company would have the right to expect a higher rate in the first case.

Minutes of Meeting of the Institute

Meeting of the American Institute of Electrical Engineers, held in the Assembly Room, New York Edison Company, 44 West Twenty-seventh St., New York, Friday, December 28, 1906. President Sheldon called the meeting to order at 8:30 o'clock.

The Secretary announced that at the meeting of the Board of Directors held during the afternoon there were seventy-seven Associates elected, as follows:

ADAMS, ROBERT WINTHROP, Electrical Engineer, D. & W. Fuse Co., 156 Melrose St., Providence, R. I.

ADES, LEWIS HENRY, Testing Laboratory, Chicago Edison Co.; res., 6401 Yale Ave., Chicago, Ill.

ALLARD, ARTHUR, Assistant Engineer Mexican Light and Power Co., Juan Carbonero 48, Mexico City, D. F. Mexico.

Allen, Arthur Elliott, Assistant Foreman, Meter Test Department, Westinghouse Electric and Mfg. Co. Newark, N. J.

Alvord, Raymond Martin, Salesman, General Electric Co.; res., 2314 Channing Way, Berkeley, Cal.

Barber, Ira Wilson, Superintendent Electric Light and Power Plant, Municipal Light and Power Plant, Mount Airy, N. C.

Bauer, Walter Henry, Salesman, Ft. Wayne Electric Works, 403 Atlas Bldg., San Francisco, Cal.

Blalock, Ira Allen, Chief Electrician Florida East Coast Railway Co., St. Augustine, Fla.

Brown, Edward Claude, Inspector, Electric Department, N. Y. C. & H. R. R R.; res., 206 E. 58th St., New York City.

Brown, Harry Arthur, Assistant Development Engineer, Central District and Printing Telegraph Co., Pittsburg, Pa.

Browne, Robert Lewis, Experimenter, Cooper Hewitt Electric Co.; res., 169 W. 91st St., New York City.

Buchanan, John Lee, Electrical Engineer, General Electric Co., Schenectady, N. Y.

Buechner, Carl August, Student, Polytechnic Institute of Brooklyn; res., 225 83d St., Brooklyn, N. Y.

Burnham, Joseph Lloyd, Designing Engineer, General Electric Co.; res., 29 Chestnut St., Schenectady, N. Y.

Buxton, Raymond Elmer, Production Clerk, Stanley G. I. Electric Mfg. Co., Pittsfield, Mass.

Carle, Nathaniel Allen, Engineer and Construction Superintendent, Westinghouse, Church, Kerr & Co., 606 Mercantile Bldg., Denver, Colo.

Coggeshall, Robert Farrington, Commercial Staff, Stanley G. I. Electric Mfg. Co., res.; 44 Pomeroy Ave., Pittsfield, Mass.

Cole, James Levern, Assistant Foreman, Westinghouse Electric and Mfg. Co., Newark, N. J.

Crosse, Shirley Robbins, Assistant in Electrical Engineering, Harvard University; res., 25 Ware St., Cambridge, Mass.

Davis, Frederick Reynolds, Advertising Department, General Electric Co.; res., 1208 State St., Schenectady, N. Y.

Day, Maxwell W., Assistant Engineer Power and Mining Department, General Electric Co.; res., 26 Rugby Road, Schenectady, N. Y.

Denton, Alpheus Penn, Special Employee, Testing Department, General Electric Co.; res., 841 Union St., Schenectady, N. Y.

Deppeler, John Howard, Inspector, N. Y. C. & H. R. R R.; res., 12 N. 16th St., East Orange, N. J.

Eberhardt, Otto Immanuel, Designer, Crocker-Wheeler Co., Ampere; res., 183 N. 16th St., East Orange, N. J.

Emerson, Henry Bennett, Engineer, General Electric Co.; res., 216 Parkwood Blvd., Schenectady, N. Y.

Foster, Marcus Lucueas, Jr., Engineer Apprentice, Westinghouse Electric and Mfg. Co.; res., 403 Gray Bldg., Wilkinsburg, Pa.

Fry, August J., Construction man, Arnold Co., 181 La Salle St.; res., 182 Oak St., Chicago, Ill.

Fussell, Lewis, Assistant in Electrical Engineering, University of Wisconsin; res., 202 Park St., Madison, Wis.

Gough, Cale Robert, Editorial Staff, Street Railway Journal, 1139 Monadnock Bldg.; res., 390 E. 66th St., Chicago, Ill.

Hamblin, Merton Ogilva, Repairman, Commonwealth Power Co., 620 Grace St., Kalamazoo, Mich.

HARTRATH, ARMIN, Editor, *Electrical Record*, Buyers' Reference Co., 123 Liberty St.; res., 23 W. 12th St., New York City.

HAWKINS, ELBERT ALLEN, Telephone Engineer, Western Electric Co., 463 West St., New York City.

HENSHAW, ARTHUR WILLISTON, Manager Motor Department, Stanley G. I. Electric Mfg. Co.; res., 30 Wendell Ave., Pittsfield, Mass.

HURLBUT, HENRY S. G., Engineering Apprentice, Westinghouse Electric and Mfg. Co.; res., 1202 Franklin St., Wilkinsburg, Pa.

JOHNSTON, ANDREW LANGSTAFF, JR., Testing Department General Electric Co., Schenectady, N. Y.

KIMBALL, EDWIN ELLIOTT, Railway Engineering Department, General Electric Co.; res., 108 Park Place, Schenectady, N. Y.

KOUWENHOVEN, WILLIAM BENNETT, Assistant in Physics, Polytechnic Institute; res., 8 Kouwenhoven Pl., Brooklyn, N. Y.

LEE, CAZENOVE GARDNER, JR., Student, Cornell University; res., 1½ Central Ave., Ithaca, N. Y.

LESLIE, EDWARD ANDREW, Student Polytechnic Institute; res., 262 Hancock St., Brooklyn, N. Y.

LYTCH, EDMOND SHAW, Electrician, Prairie Pebble Phosphate Co., Mulberry, Fla.

McCANDLESS, WILSON, Treasurer, United Electric Construction Co., 1714 Sansom St., Philadelphia; res., 2051 N. 63d St., Overbrook, Pa.

MENTZ, HENRY ALVAN, Electrical Engineers' Office, B. & O. R.R., Central Bldg., Baltimore, Md.

MILLAR, LESLIE WALKER, Inspector, Edison Electric Illuminating Co., 516 Atlantic Ave., Boston; res., 43 Clyde St., Newtonville, Mass.

MITCHELL, GUY K., Consolidated Gas Electric Light and Power Co., N. W. Lexington and Liberty Sts.; res., 1046 Argyle St., Baltimore, Md.

MORGAN, WILLIAM DUNCAN NICOLL, Chief Engineer, Scottish Central Electric Power Co. and Lothians Electric Power Co., 34 North Bridge Edinburgh, Scotland.

MURPHY, JAMES EDWARD, Brooklyn Rapid Transit Co.; res., 8414 Fort Hamilton Ave., Brooklyn, N. Y.

NIELSON, JULIAN JACOB, Draughtsman, J. L. Schureman Co.; res., 649 Irving Park Blvd., Chicago, Ill.

OGDEN, KARL RANDALL, Field Engineer, Central District and Printing Telegraph Co., Pittsburg, Pa.

PALMER, ALBERT NICKERSON, Electrical Engineer, Phillips Insulated Wire Co., Pawtucket, R. I.

PATTON, WILLIAM FEARN, JR., Engineering Apprentice, Westinghouse Electric and Mfg. Co.; res., 403 Gray Bldg., Wilkinsburg, Pa.

PETERSEN, PETER CONRAU, 19 John St., Muskegon, Mich.

POST, ARTHUR WOOD, Student, Brooklyn Polytechnic Institute, Brooklyn res., Westbury, L. I., N. Y.

POWELL, PERCIVAL HERBERT, Lecturer and Demonstrator in Electrical Engineering, School of Engineering, Canterbury College, Christchurch, N. Z.

PROUD, OWEN E., Electrician, Philadelphia Terminal, Pennsylvania R R. Co., 1518 Filbert St.; res., 1152 N. 62d St., Philadelphia, Pa.

PUTNAM, WILLIAM ALGER, Chief Engineer, City Electric Light and Power Co., Tallahassee, Fla.

RODDEY, JOHN HARVEY, Assistant Engineering Department, Southern Power Co., Charlotte, N. C.

ROSE, GEORGE STANTON, General Electric Co.; res., 841 Union St., Schenectady, N. Y.

RUSH, FLETCHER GRAY, Electrical Inspector, South Eastern Tariff Association, 1010 First National Bank Bldg., Birmingham, Ala.

SANBORN, ARTHUR ROSCOE, Expert Electrical Aid, Office of Superintending Naval Constructor, William Cramp and Sons, Philadelphia, Pa.

SHEAR, VERNE WARREN, Tester. Westinghouse Electric and Mfg. Co. res., 1128 Franklin Ave., Wilkinsburg, Pa.

SHEPARD, LYMAN, Superintendent, Electric Light and Water Works, Edenton, N. C.

SLOANE, WILLIAM WOODARD, Draftsman, Western Electric Co.; res., 1330 Washington Blvd., Chicago, Ill.

SMITH, ARTHUR R., Electrical Engineer, General Electric Co.; res., 621 Terrace Pl., Schenectady, N. Y.

SMITH, DANIEL SANFORD, Electrical Engineer, General Electric Co., 44 Broad St., New York City; res., 270 Hewes St., Brooklyn, N. Y.

SMITH, ELLIS BURTON, Assistant Factory Engineer, Western Electric Co., 463 West St., New York City; res., 82 North 15th St., Newark, N. J.

SPENCER, EUGENE JACCARD, Consulting Engineer, 400 Merchants' Laclede Bldg., St. Louis Mo.

STENGER, LAURENCE A., Engineering Staff, Twin City Rapid Transit Co.; res., 1613 4th St. S. E., Minneapolis, Minn.

TAGGART, RALPH CONE, Associate Engineer, Wm. J. Baldwin; res., 311 W. 95th St., New York City.

UPTEGRAFF, WALTER DENNY, Second Vice-President and Treasurer, Nernst Lamp Co., Westinghouse Bldg., Pittsburg, Pa.

URBAN, HENRY, Engineer, Societe Generale de Chemins de Fer Economiques, 22 Rue Gachard, Brussels, Belgium.

VAN VALKENBURG, ASA T., Erecting Engineer, Westinghouse Machine Co., 171 La Salle St., Chicago, Ill.

VON DANNENBERG, CARL OTTO, Assistant Electrical Engineer, Electrical Engineering Department, Columbia University, New York; res., 22 Townsend Ave., Stapleton, N. Y.

WAGNER, WALTER CALVIN, Instructor and Student, University of Washington; res., 6000 Corliss Ave., Seattle, Wash.

WHARFF, EDWARD MANSFIELD, Apprentice, Rochester, Syracuse and Eastern R R.; res., 15 High St., Newark, N. Y.

WIMAN, LOUIS ERASTUS, Engineering Department, General Electric Co.; res., 1 State St., Schenectady, N. Y.

WOOD, HOWARD JOHN, Chief Draftsman, Office Electrical Engineer B. & O. R R. Co., Baltimore and Charles Sts.; res., 1725 N. Monroe St., Baltimore, Md.

WRIGHT, EDWARD ALBIN, Student, Cornell University; res., 58 Thurston Ave., Ithaca, N. Y.

Total, 77.

The Secretary announced further that the Institute membership is invited to attend the monthly meeting of the American Society of Mechanical Engineers, to be held in the Engineers' Building, 33 West 39th Street, on January 8th. Frederick P. Fish, Esq., president of the American Telephone & Telegraph Company, will address the meeting on the subject of " The Ethics of Trade Secrets in Relation to the Patent System."

PRESIDENT SHELDON: I should like to bespeak the assistance of the members present towards the efforts which are being made by the Committee for the Increase of Membership, Mr. Thomas, chairman. Through the efforts of this committee, 77 new Associates were elected to-day, and there are 150 applications in the office going through the process of posting and making ready for election. The Institute is a body representative of the electrical engineering profession; such is its position, but it cannot be so in fact unless its membership and enrolment is representative of the profession at large. There is a large number of eligible non-members, and I would ask your assistance in persuading some of these, consistent with your dignity and the dignity of the Institute, to join our ranks.

Institute Meetings

The following schedule has been prepared by the Committee on Papers subject to possible change due to unforeseen contingencies:

February Meeting, March 1, 1907.
Alternating-Current Electrolysis, by J. LeR. Hayden.
Electrolytic Corrosion of Iron and Steel in Concrete, by A. A. Knudson.

March Meeting, March 29, 1907.
Lightning and Lightning Protection, by C. P. Steinmetz, E. E. F. Creighton, and D. B. Rushmore.

April Meeting, April 26, 1907.
Rowland Telegraphic System and its Apparatus, by Frank M. Potts.

May Meeting, May 24, 1907.
Turbo-Alternators, by B. A. Behrend.
Zigzag Leakage of Induction Motors, by R. E. Helmund.

Annual Convention:
Some Power Transmission Economics, by F. G. Baum.
Notes on Transformer Testing, by H. W. Tobey.
One-Phase, High-Tension Power Transmission, by E. J. Young.
Ten Years of Niagara Power, by H. B. Alverson.
Fractional Pitch Windings for Induction Motors and Alternators, by C. A. Adams.
Attitude of Technical Schools Toward the Profession of Electrical Engineering, by H. H. Norris, and Valdemir Karapetoff.
Engineering Specifications, by C. W. Ricker.
Vector Diagrams of One-Phase Commutating Motor, by W. I. Slichter.

Meetings A.S.M.E.

Future monthly meetings of the American Society of Mechanical Engineers will be held in the Auditorium of the Engineers' Building, 29 West Thirty-ninth Street, New York City, as follows:

February 12, Professor C. M. Allen, Professor of Experimental Engineering, Worcester Polytechnic Institute; Subject: "Gasolene," with special reference to its use in the Automobile; illustrated by experiments.

March 12, Address by John W. Lieb, Jr., Vice-president A. S. M. E., and Past-president A. I. E. E. Subject: "Vesuvius and Pompeii," illustrated by lantern slides.

April 9, (This date may be changed.) Addresses by Brigadier-General Arthur-Murray, U. S. A. and Brigadier-General William Crozier, U. S. A. Subject: "The coast defences of the United States."

Members of the American Institute of Electrical Engineers will be welcome at any of these meetings.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting.

Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before March 1, 1907.

5585 Charles Auth, Brooklyn, N. Y.
5586 R. B. Benjamin, Chicago, Ill.
5587 F. D. Burr, Canyon Ferry, Mont.
5588 D. J. Butts, New York City.
5589 H. C. Buck, Chicago, Ill.
5590 A. W. K. Billings, Havana, Cuba.
5591 L. Carpenter, Colorado Spgs., Col.

5592 Wm. C. Coles, Atlanta, Ga.
5593 T. V. d'Ornellas, Lima, Peru.
5594 L. P. Dickinson, Easton, Pa.
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5719 J. R. Wagner, New York City.

Total, 135.

Applications for Transfer

Recommended for transfer by the Board of Examiners, Jan. 11, 1907.

Any objection to these transfers should be filed at once with the Secretary.

L. S. Randolph, Consulting Engineer, Blacksburg, Va.

Albert Cavallo Jewett, Electrical Adviser to Government Kashmir (India) Baniar, Jhelum Valley Road, Kashmir, India.

William Corbit Spruance, Jr., Consulting Engineer, Equitable Building, Wilmington, Del.

Harry Ellsworth Clifford, Professor of Theoretical Electricity, Massachusetts Institute of Technology, Boston, Mass.

Edgar Davis Edmonston, Chief Engineer American Construction Co., New Orleans, La.

George Roy Wood, Consulting Electrical Engineer, 1021-1023 Fulton Bldg., Pittsburg, Pa.

Lee de Forest, Wireless Telegraph Development, 315 West 97th St., New York City.

William C. L. Eglin, Electrical Engineer Philadelphia Electric Co., 10th and Sansom Sts., Philadelphia, Pa.

Peter Cooper Hewitt, Scientist, 11 Lexington Ave., New York City.

Personal

Mr. H. L. Van Valkenburg is now with the Walker Electric Company, Philadelphia, Pa., as chief engineer.

Mr. F. M. Shepard has removed from Fanwood, N. J., to Madison, Wis., with the Northern Electrical Mfg. Co.

Mr. Nathaniel M. Snyder has gone from Lincoln, Neb., to 192 Dearborn Ave., Kankakee, Ill.

Mr. Norman McD. Crawford has removed from Hartford, Conn., to Cincinnati, O.

Mr. J. J. Kline has changed his address from Chicago to the Fort Wayne Electric Works, Fort Wayne, Ind.

Mr. M. C. Turpin, formerly at Philadelphia, Pa., is now with the Auburn Light, Heat and Power Co., Auburn, N. Y., as superintendent.

Mr. P. Eveland has left the General Electric Company and is now with the Leadville Light and Power Company, Leadville, Colo.

Mr. Clarence F. Hirshfeld, of Ithaca, N. Y., has been appointed assistant professor of power engineering at Cornell University.

Mr. Franklin Punga has removed from Oswaldstre House, London, Eng., to Gundeldingerstrasse, 87, Bale, Switzerland.

Mr. Howard S. Wilson, electrical engineer, of Baltimore, Md., is now with the Submarine Signal Company, 88 Broad St., Boston, Mass.

Mr. D. McNicol has removed from the Postal Telegraph Cable Co. at Butte, Mont., to that company's office at Salt Lake City, Utah.

Mr. M. C. McKay has left Oakland, Cal., to take the position of superintendent American River Electric Co., at Stockton, Cal.

Mr. H. B. Kirkland, sales manager American Loom Company, Chelsea, Mass., has left that concern to take a similar position with the National Metal Molding Co., of Pittsburg, Pa.

Mr. Harry O. F. Bindemann, formerly chief engineer Gasifacion Industrial, Madrid, Spain, is now chief engineer for the Rhinisch-Westfalian Electricity Works, of Essen-Ruhr, Germany.

Mr. A. W. Stuntz has gone from Wilkinsburg, Pa., to Alliance, O., being connected with the Morgan Engineering Company of that city, in the capacity of designing electrical engineer.

Mr. A. L. Cook, formerly assistant instructor at Pratt Institute, Brooklyn, N. Y., is now connected with Westinghouse, Church, Kerr & Co., of New York, as engineer.

Mr. Irving H. Sherwood, has left the People's Light and Railway Company, Streator, Ill., and is with the Roberts and Abbott Company, Cleveland, O.

Mr. W. B. Gump has removed from Buffalo, N. Y., to Cleveland, O., to occupy the position of designing engineer for the Cleveland Construction Company.

Mr. Claude A. Bulkeley, formerly Inspector United States Treasury Department at Washington, D. C., has been appointed chief engineer Board of Education, St. Louis, Mo.

Mr. Charles E. Bennett, formerly with the New York Central and Hudson River Railroad, is now on the staff of L. B. Stillwell, 100 Broadway, New York.

Mr. John B. Ingersoll has become general manager and chief electrical engineer of the Spokane and Inland Railway, Spokane Terminal Co., at Spokane, Washington.

Mr. Charles M. Blanchard, formerly chief electrician Lackawanna Coal and Coke Company, Wehrum, Pa., has changed to the Black Band Coal and Coke Company, Chilton, W. Va., as general superintendent.

Mr. John S. Wise, formerly assistant superintendent of the Auburn Light, Heat and Power Co., Auburn, N. Y., has become general manager of the Consumers' Electric Light and Power Company, at Hazleton, Pa.

Mr. F. W. Newell, connected with the electrical engineering department of the Otis Elevator Company, has gone from the Yonkers N. Y., office, to the office of the same company, West End Trust Building, Philadelphia, Pa.

Mr. W. R. Horning, formerly engineer of Williams Telephone and Supply Co., of Cleveland, O., has accepted the position of branch manager with Robbins and Myers Co., of Springfield, O., at the Cleveland office.

Mr. Clarence A. Stimpson has changed from the Postal Telegraph Cable Co., 1326 Chestnut Street, Philadelphia, to the Installation Bureau of the Philadelphia Electric Co., 122 Arch St., Philadelphia, Pa.

Mr. Louis W. Pratt, Local Secretary at Toronto, Ont., has left the Brantford Electric and Operating Co., at Brantford, Ont., to go with The Federal Electric Construction Co., Ltd., of Toronto.

Mr. John W. Kelly, Jr., recently Superintendent of Equipment, Keystone Telephone Co., Philadelphia, Pa., is now general superintendent, General Acoustic Co., 1265 Broadway, New York City.

Mr. Frederick H. Coble, formerly electrical engineer with the Testing Bureau, Brooklyn Heights Railroad Company, is now associated with L. B. Stillwell as assistant to superintendent of power and construction, at Baltimore, Md.

Mr. J. H. Smith has resigned the managership of *The Electrical Journal* at Pittsburg, and purchased the Electrical Age Company, publishers of *The Electrical Age*. The publication offices have been removed to 45 East Forty-second Street, New York City.

Mr. F. J. Foote, for two years electrical and mechanical engineer with the manufacturing interests represented by the American Oak Leather Co., has accepted a position on the engineering staff of the Westinghouse Electric and Manufacturing Co., at Cincinnati, O.

Mr. R. W. Hutchinson, Jr., consulting engineer, and now on the staff of the National Brake and Electric Co., Milwaukee, has written a technical work on Long Distance Electric Power Transmission, published by the D. Van Nostrand Company, New York City.

Mr. Frank G. Baum, who has been in charge of the hydraulic and electrical engineering and construction, and also the operation, of the system of the California Gas and Electric Corporation for the past three and one-half years, has resigned his position and gone into consulting engineering; his specialty being hydroelectric power plants and long-distance transmission systems. Mr. Baum will continue as consulting engineer for the California Gas and Electric Corporation. His offices are in the Chronicle Building, San Francisco, Cal.

Obituary

Francis E. Jackson died on Thursday, November 7, 1906, at the home of his father in East Orange, N. J.

He was born in Brooklyn in 1865, but lived almost his entire life in East Orange. From the public schools of East Orange he entered the class of '86 of Stevens Institute, and, after graduation, entered the employ of the Edison Lamp Company, of Harrison, N. J. During his connection with this company he was also an inspector of lighting plants for the Association of Edison Illuminating Companies. In 1894 he left the above company and began the manufacture of incandescent lamps in Newark, N. J., and in the same year a separate plant for the manufacture of incandescent lamp filaments in Orange, N. J. At a later date he manufactured fluorescent screens for X-ray work. He was a life member of the Stevens Institute Alumni Association and the Y. M. C. A., an active member of the Canoe Brook Country Club and Roseville Golf Club. He was elected an Associate of the Institute January 3, 1888, and transferred to the grade of Member June 17, 1890.

For over two years previously to his death he had been unable to attend closely to business, and his health continued to fail steadily until his death.

Albert Earle Hayes, elder son of Wylon G. and Nettie A. Hayes, of Fitchburg, Mass., died at his home in that city December 24, 1906. Mr. Hayes was born July 12, 1877, and was graduated from the Worcester Polytechnic Institute in 1898 with the degree B.S. in electrical engineering. Beginning August 1898, he spent nine months with the Anchor Electric Company of Boston. He subsequently entered the service of the General Electric Company at the Lynn works, and after a year in the testing department, was transferred to the alternating department on the design of constant-current series alternating transformers and kindred apparatus. In February 1906 he was transferred to Schenectady, where he was placed in charge of the design of constant-current transformers. In August 1905 his right leg was accidentally fractured, and in the following December amputation was necessary. Although he resumed work in April, his health began to decline, and in August he was obliged to relinquish active work, returning to his home in Fitchburg.

Mr. Hayes was for several years connected with the General Electric Engineering Society at Lynn, of which he had been vice-president and secretary. He was elected an Associate of the Institute August 17, 1904. The survivors of his family are his parents, a sister, Miss Ruth M. Hayes and his younger brother, Clifton R. Hayes of Ludlow, Mass., who is also an Associate of the Institute.

ERNEST EDGAR DAVIS, senior partner of the Davis-Forrest Machine Works at Savannah, Ga., died in Baltimore, December 25, 1906. Mr. Davis was a son of Mr. Thomas J. Davis, and was born in Savannah, September 5, 1873. He was graduated from the Georgia School of Technology 1893, degree of M.E., and took a post-graduate course at the Ohio State University with the degree of E.E. 1896. At the World's Fair, Chicago, 1893, he served for four months as assistant to the judges in the electrical department. Returning to Savannah he worked as day engineer for the Brush Electric Light and Power Company until the beginning of his post-graduate course in 1895. In 1898 he established the Davis Machine Works, which he carried on successfully, forming in 1902 with G. F. Forrest a partnership known as the Davis-Forrest Machine Works, Incorporated, engineers and machinists. About three years ago his health became impaired, making it necessary for him to resort to medical treatment. He was for a time in the Johns Hopkins Hospital in Baltimore, and after a few months at home, returned to Baltimore where his health seemed better and he was employed by the T. H. Lymington Company until his death on Christmas day. The surviving members of his family are his father, his brother, William V. Davis, and three sisters.

Mr. Davis was elected an Associate November 20, 1903, and his correspondence indicates that he heartily appreciated his membership.

WALLACE CLYDE JOHNSON, consulting engineer on water power development and electric transmission, died at his home in Niagara Falls, N. Y., December 15, 1906. Mr. Johnson was born in Granville, Mass., May 21, 1859. He was graduated from the Worcester Polytechnic Institute with the degree of B.S. in 1884. He was assistant engineer of the Holyoke Water Power Company from 1884 to 1886, and chief engineer of the Niagara Falls Hydraulic and Manufacturing Company from 1886 to November 1900. During the latter period he designed and constructed the first power house of that company, having a capacity of 30,000 horse power. This was used to drive direct-current generators of 20,500 kw. and an alternating-current generator of 700 kw. capacity. He also built several electric light plants, among which was that of the Albion (N. Y.) Power Company of which he was engineer and general manager. On November 1, 1900, he was appointed chief engineer of the Shawinigan Water and Power Company and was engaged in the development of about 100,000 horse power, the installation of several 3750 kw. alternators, and construction of eighty miles of transmission line. He was also consulting engineer for the Nannawa Falls Water Power Company of Potsdam, N. Y., and the Pittsburg Reduction Company. Mr. Johnson was elected an Associate March 22, 1901.

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LOCAL ORGANIZATIONS—DIRECTORY.

Branches Organized.	Chairman.	Secretary.	Branch Meets.
BRANCHES.			
Atlanta............Jan. 19, '04	A. M. Schoen.	W. R. Collier.	
Baltimore.........Dec. 16, '04	J. B. Whitehead.	C. G. Edwards.	2d Friday.
Boston............Feb. 13, '03	H. E. Clifford.	C. H. Porter.	3d Wednesday
Chicago..................1893	P. B. Woodworth.	H. R. King.	1st Tuesday after N. Y. meeting.
Cincinnati.........Dec. 17, '02	C. S. Reno.	L. Lowenberg.	
Columbus.........Dec. 20, '03	F. W. C. Bailey.	H. L. Cook.	1st Mondays
Minnesota..........Apr. 7, '02	Edward P. Burch.	Barry Dibble.	1st Friday after N. Y. meeting.
Pittsburg..........Oct. 13, '02	H. W. Fisher.	H. D. James.	2d Tuesday.
Pittsfield..........Mar. 25, '04	Gilbert Wright.	S. H. Blake.	3d Thursday.
Philadelphia.......Feb. 18, '03	W. C. L. Eglin.	H. F. Sanville.	2d Monday.
San Francisco......Dec. 23, '04	C. L. Cory.	A. H. Babcock.	
Schenectady.......Jan. 26, '03	D. B. Rushmore.	E. E F. Creighton.	2d Wednesday.
Seattle............Jan. 19, '04	C. E. Magnusson.	W. S. Wheeler.	2d Tuesday.
St. Louis..........Jan. 14, '03	A. H. Timmerman.	A. S. Langsdorf.	2d Wednesday.
Toronto..........Sept. 30, '03	R. G. Black.	L. W. Pratt.	2d Friday.
Washington, D. C...Apr. 9, '03.	Edgar Russel	Philander Betts.	1st Thursday.
UNIVERSITY BRANCHES.			
Cornell University..Oct. 15, '02	E. L. Nichols.	H. H. Norris.	1st Friday after N. Y. meeting.
Iowa State College..Apr. 15, '03	F. A. Fish.	Adolph Shane.	1st Wednesday.
Lehigh University..Oct. 15, '02	A. W. Lawson.	M. T. Saldana.	3d Thursday
Purdue University..Jan. 26, '03	C. P. Matthews.	J. W. Esterline.	Every Tuesday.
Syracuse University Feb. 24, '05	W. P. Graham	G. C. Baker.	1st and 3d Thursdays.
Univ. of Wisconsin.Oct. 15, '02	F. M Conlee.	J. W. Shuster.	4th Thursday.
Univ. of Illinois....Nov. 25, '02	Morgan Brooks.	M. K. Akers.	1st Wednesday
Worcester Polytechnic Institute, Mar. 25, '04	A. P. Chapman.	A T. Childs	
STUDENT MEETINGS.			
Armour Institute...Feb 26, '04	C. E. Freeman	C. E. Freeman	3d Monday
Ohio State Univ....Dec 20, '02	H. C. Bartholomew	F. E. Beutler	Every Tuesday evening
Penn. State College.Dec 20, '02	C. L. Christman	H. L. Frederick	Every Wednesday
Univ. of Arkansas..Mar 25, '04	W. B. Stelzner.	G. C. Baker.	1st & 3d Tuesdays
Univ. of Michigan..Mar 25, '04	Kenneth Barry	C. J. Whipple.	1st and 3d Wednesdays
Univ. of Missouri...Jan 10, '03	H. B. Shaw	H. D. Carpenter.	1st and 3d Fridays
Washington Univ...Feb 26, '04	A. S. Langsdorf	W. E. Bryan.	1st Wednesday

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

Published monthly at 33 W. 39th St., New York City, under the supervision of

THE EDITING COMMITTEE,

THOS. J. JOHNSTON, Chairman.
GANO DUNN. CECIL P. POOLE.

RALPH W. POPE, Editor.

Subscription. United States, Canada, Mexico and Cuba, $5 per year.
All other countries $6 per year.
Single copy 50 cents.
Subscriptions must begin with January issue.

Advertisements accepted from reputable concerns at the following net rates:

Space.	**Less than half year.** per issue.	**Half year.** per issue.	**One year.** per issue.
1 page	$36.00	$32.00	$30.00
½ page	22.00	18.00	16.00

Additional charges for Preferred Positions.
Professional Cards, special rate of $25 per year.

Vol. XXVI. **February, 1907.** No. 2.

Institute Headquarters

EXPERIENCE in the actual occupation of the suite of offices in the Engineers' Building shows that when all details are finished the quarters will be entirely satisfactory. The rooms are spacious and light, with a fine view of the city in every direction, as well as Long Island, New Jersey, and the North and East Rivers. At the first glance, many think the rooms are unnecessarily large, but it should be remembered that the building has been planned for the future as well as the present. During one afternoon of the first week of occupancy, the Board of Examiners, the Edison Medal Committee, and a subcommittee on Standardization Rules, met simultaneously in the Committee Room, the Reception Room, and the Board Room. Under previous conditions this would have been impossible. As already announced, the actual transfer from the Liberty Street quarters was made on Saturday, February 2, so that on the following Monday, the new offices were occupied. The moving of the library was interfered with by the heavy snow which began falling on Monday. After the books were removed, the stacks were taken down and re-erected in the stack room on the twelfth floor. In order to prevent confusion care must be exercised in replacing the books upon the proper shelves, so that much more time is necessarily consumed in this work. Arrangements were made for the temporary use of another reference library while the change was being made, so that visitors have not been neglected. The selection and purchase of furniture and carpets, and the contract for moving the entire equipment has been in charge of the Library Committee. The work has been carried out satisfactorily in every detail by the office staff.

The Railway Meeting

THE first Institute meeting held in the main auditorium was that of January 25. The subject of the paper, the standing of the authors, Messrs. Stillwell and Putnam, the general interest in the electric railway situation, combined with a natural desire to test the practical qualities of the hall, served to attract an audience of about twelve hundred, the largest number ever attending a meeting of the Institute. The seating capacity of this auditorium is one thousand, which may, however, be slightly increased in the future by an additional row of seats. Seats may also be temporarily placed at the four double doors in the corridor which completely encircles the hall. The acoustic properties of the room are fine, the coat-room accommodations ample, and every possible detail has been carefully worked out. Judging from the experience of one meeting, engineers are to be congratulated upon the successful solution of a problem which has always confronted them in New York as well as in many smaller cities. The close attention which was given to the words of all the speakers was sufficient evidence of the interest shown by the auditors.

The Age Limit

OCCASIONAL objections are raised against the constitutional requirement that applicants for transfer from the grade of Associate to that of Member shall have reached the age of twenty-seven years. There was no restriction of this character in the constitution which was superseded in 1901. It was however found in practice, that young men were prone to apply for transfer immediately after graduation, and that the time of the Board of Examiners was occupied to an unnecessary extent in considering these applications which could not be recommended on account of lack of electrical engineering experience of a proper quality. It was recognized that there might be occasional exceptions to the rule, but they have proved to be exceedingly rare. Other engineering societies have fixed a similar limit at the age of thirty years.

The fixing by law of an age limit is a very common practice, and while in many instances it may appear to be a hardship, it is a simple method for the purpose of determining at the outset that the applicant has acquired the essential amount of experience.

SOME members are not so careful as they should be in returning promptly the endorsement forms mailed to them upon the suggestion of candidates for election or transfer. When inquiry is made as to delay in action upon a case, it is embarrassing to the applicant to learn that any of his references have failed to reply. A stamped envelope is sent for this purpose, and ordinary courtesy should be a sufficient incentive to elicit a reply even if it be unfavorable. Every month it is found necessary to send out duplicate forms, which involves additional expense, as well as trouble, delay, and annoyance.

THE annual volume for 1906 will not be ready for distribution before the first of June. It is desirable that all discussions should, if possible, be included with the paper to which they belong, in the same book. This prevents the immediate completion of the volume at the close of the calendar year. The actual contents having already appeared in the monthly issues, this unavoidable delay is not so serious a matter as it would be if the papers were not immediately available after presentation. The monthly parts should be filed for reference until the bound volume is received.

IN the list of members sent out with the nomination papers, the file numbers given are those of the office folders assigned to each member. These numbers are permanent, and those who care to remember them, may facilitate the office routine by affixing the proper file number to each letter when corresponding with the Institute. This is a mere suggestion; but, when followed, it will save the time necessary for consulting the index in each case; and if correctly given will avoid errors in filing. The same number will also be printed with the address on the mailing machine. As the mailing addresses have been copied from the old list, members are requested to notify the Secretary in case any errors have been made.

WHILE the Institute office is not officially known as a Bureau of Information, inquiries are frequently received from non-members as well as members who desire to obtain copies of papers of which only the vaguest details are given. Fortunately the library usually affords facilities for answering these inquiries, if in the line of electrical or mechanical engineering. Even a request for the name of an electrical engineer who was also a good baseball pitcher has been complied with, but continual success in such searches must not always be expected.

Steam Power Station, Twin City Rapid Transit Company Minneapolis, Minn.*

The plant described herein is the steam power station of the Twin City Rapid Transit Company, which operates in parallel with a water power station of 10,000 h.p. capacity located approximately 1000 ft. away. Together they furnish power to ten electric railway sub-stations, which are equipped as follows:

Sub-stations	Distance in feet.	Converters	Capacity in kilowatts
Eleventh St., Minneapolis	11,350	4	6,000
Water Power, Minneapolis		4	2,400
Lake St., Minneapolis	13,900	2	3,000
College Ave., St. Paul	43,900	4	6,000
Snelling Ave., St. Paul	25,200	2	3,000
Wildwood	100,200	3	1,800
Stillwater	136,400	1	600
Hopkins	57,250	3	1,800
Excelsior	103,050	3	1,800
Big Island	109,400		600
		26	27,000

Eleventh St. and College Ave. sub-stations are equipped with relatively small storage-batteries, each rated at 1600 amperes, 600 volts, on a one-hour discharge basis.

Each power station furnishes about one-half the total output in kilowatt-hours, the steam station taking the variations in the load as shown on the accompanying typical load curve.

STEAM POWER PLANT BUILDING.

Location. East bank of Mississippi river, just below the Tenth avenue bridge, Minneapolis.

Size. 155 ft. 11 in. wide by 255 ft. 2 in. long by 93 ft. high from engine-room basement to roof.

Engine-room. 67 ft. wide, extending full length of building, and 56 ft. high in the clear; basement floor 20 ft. below engine-room floor.

Boiler-room. 83 ft. wide and full length of building; basement floor 14 ft. below boiler-room floor; boiler-room floor 4 ft. above engine-room floor.

FILTRATION PLANT.

Building. 35 ft. 4 in. by 48 ft. 8 in., concrete and brick.

Intake. 8 in. hub and spigot pipe, controlled by butterfly valve.

Sedimentation tank. 24 ft. by 33 ft., with 4 baffles.

Filter-beds. Four; each 10 ft. by 13 ft., capacity 300 gal. per minute. Beds consist of 8 in. of gravel in three sizes and 28 in. of sand. Size of sand 0.56 to 0.60 mm. Guaranteed to operate three years without renewal of filtering material.

Strainer system. Each filter-bed equipped with 143 2-tube strainers and 26 3-tube strainers. Velocity of water not over 1.5 ft. per min.

Air-wash system. $\frac{3}{8}$ in. brass pipes, spaced 4 in. apart, uniformly distribute the air in each bed.

Clear well. Located underneath filter-beds.

Discharge for filtered water, 12 in. flanged wrought iron pipe.

Alum tanks. Two 5 ft. diam. by 5 ft. deep, white cedar; graduated orifice box to measure and indicate quantity of solution being used.

Wash-pump. 6 in. Lawrence centrifugal, operated by 20 h.p. motor.

Air-compressor. 12 in. by 8 in., driven by pulley on pump-shaft.

Drain-pump. Duplicate of wash-pump; operated by motor through friction-clutch.

Capacity of plant, 1200 gal. per min.

Guaranteed to remove 98 per cent. of suspended matter, filtered water to show no trace of undecomposed coagulant.

STACKS, 2.

Built of hollow radial moulded brick, each stack 162 ft. high by 16 ft. inside diameter; foundation 63 ft. above boiler-room floor; total height of stack above boiler-room, 225 ft.

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* Prepared for a meeting of the Minnesota Branch, American Institute of Electrical Engineers. December 29th. 1906.

Guaranteed to stand 50 pounds per square foot wind pressure and influence of atmosphere 800° fahr.

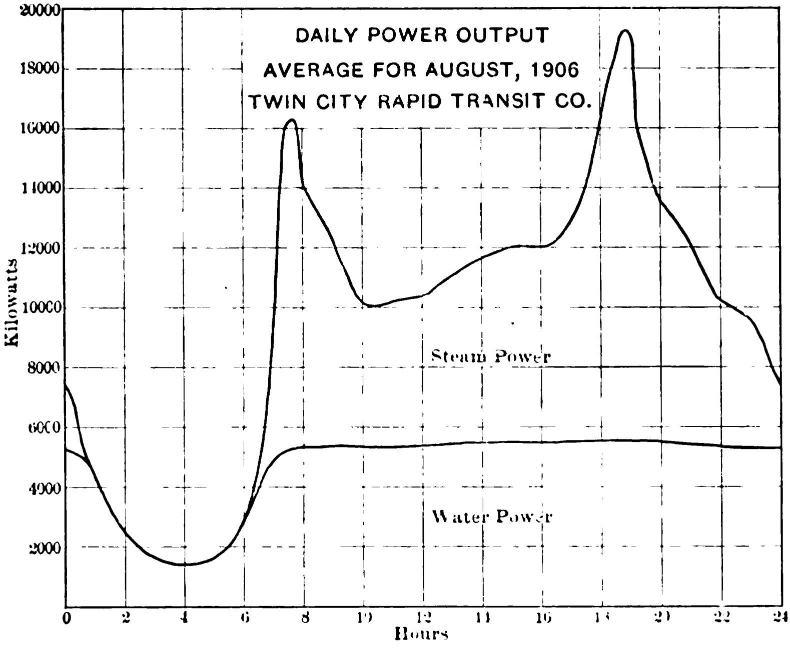
Breeching. Two flues per stack. Area of each, 125 sq. ft. at stack.

Coal Bunkers, 4.

I-beam, and cinder-concrete construction.

Aggregate capacity. 2800 tons.

Bunkers directly above boilers with light-well 14 ft. between them, the entire length of boiler-room, thus giving a light and well-ventilated room.



Each bunker feeds three batteries of two boilers each.

The bottom of each bunker has six steel hoppers, which lead to coal valves and spouts of each boiler.

Belt Conveyor.

Location. North side of station, between building wall and unloading track.

Capacity guaranteed. 75 tons coal per hr. from car to receiving hopper; speed, 280 ft. per min.

Length. 205 ft. centers.

Belt. Endless, 24 in., 4-ply, with ⅛ in. extra cover of pure rubber on carrying side.

Roller. Short type, with spring grease cup lubricators.

Guide pulleys. Spaced every 50 ft. along upper run.

Head pulley. Rubber covered.

Motor. 10 h.p., slow speed, back geared; counter shaft, 132 rev. per min., enclosed in steel box. Starting rheostat and automatic cutout.

Sideboards. 1.5 in. matched oak plank on iron frame, thoroughly coated with pitch. On track side, made in sections to lean against car.

Coal Crusher and Conveyor.

Crusher. One-drum type.

Conveyor. Overlapping gravity bucket.

Coal distribution. Consisting of one transverse conveyor receiving coal from crusher in basement of boiler-room and delivering it to two longitudinal conveyors, which elevate and distribute it to four coal bunkers above the boilers.

Ash collection. Receiving ashes from ash-hoppers in basement under the furnace and elevating and delivering them to transverse conveyor, which delivers the ashes to a hopper over coal track.

Nominal capacity. Crusher and entire conveying system, 75 tons per hr., traveling 100 ft. per min.

Buckets. 24 in. by 24 in., buckets and links of malleable iron, shafts 1.25 in. diameter, wheels 6 in. diameter, 1.5 in. tread, track 16-pound T-rail.

Drive. Electric; 600-volt, direct-current motors; crusher 25 h.p.; transverse conveyor, 7.5 h.p.; longitudinal conveyor 25 h.p., all drives located at bottom of down-takes, all tighteners ocated at bottom of up-takes.

STOKERS AND FURNACES, 24.

Automatic stokers.

Grate. Rocking, inclined, engine-driven.

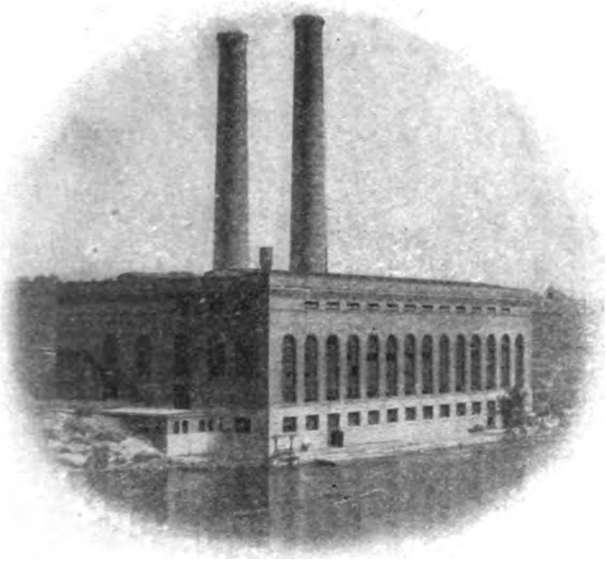
Fire arch. Single span.

Nominal Capacity. 550 h.p., standard of 34.5 lb. of water from and at 212 degrees fahr. per horse-power hour.

Overload capacity. 825 h.p. continuously.

Grate surface. 111 sq. ft.

Guaranteed to evaporate 10 lb. of water from and at 212 degrees fahr. per pound of dry coal, with ⅜ in. draft in furnace, without smoke. Under same conditions to evaporate 11 lb. of water per pound of coal, burning coal containing 14,000 B.t.u.; at 825 h.p., to evaporate 9.25 lb. of water per pound of coal containing 14,000 B.t.u.



Exterior of Power Station.

BOILERS, 24.

Wrought steel sectional tube.

Nominal capacity. 556 h.p.

Overload capacity. 825 h.p.

Working pressure. 200 lb. per sq. in.

Heating surface. 5560 sq. ft.

Flue connections. At top of setting.

Pop safety valves. Two per boiler with muffler.

Gauges. 18 in., Crosby type.

Superheater. Capable of producing

120° fahr. superheat, contained within boiler setting.

Guaranteed to operate at capacities specified with ¾ in. draft in main flue and coal containing 13,000 B.t.u. per lb.

Steam and water drums. Three, 36 in. diameter, 23 ft. 3 in. long.

Tubes. 21 sections, 13 tubes each, 4 in. diameter, 18 ft. long.

Headers. Forged steel.

Feed connection. 2.5 in. diameter.

Steam delivery outlet. 10 in. diameter.

Test. Sections 400 lb. per sq. in., drums 300 lb. per sq. in., mud drum 300 lb. per sq. in.

Weight. Total, 621,000 lb.

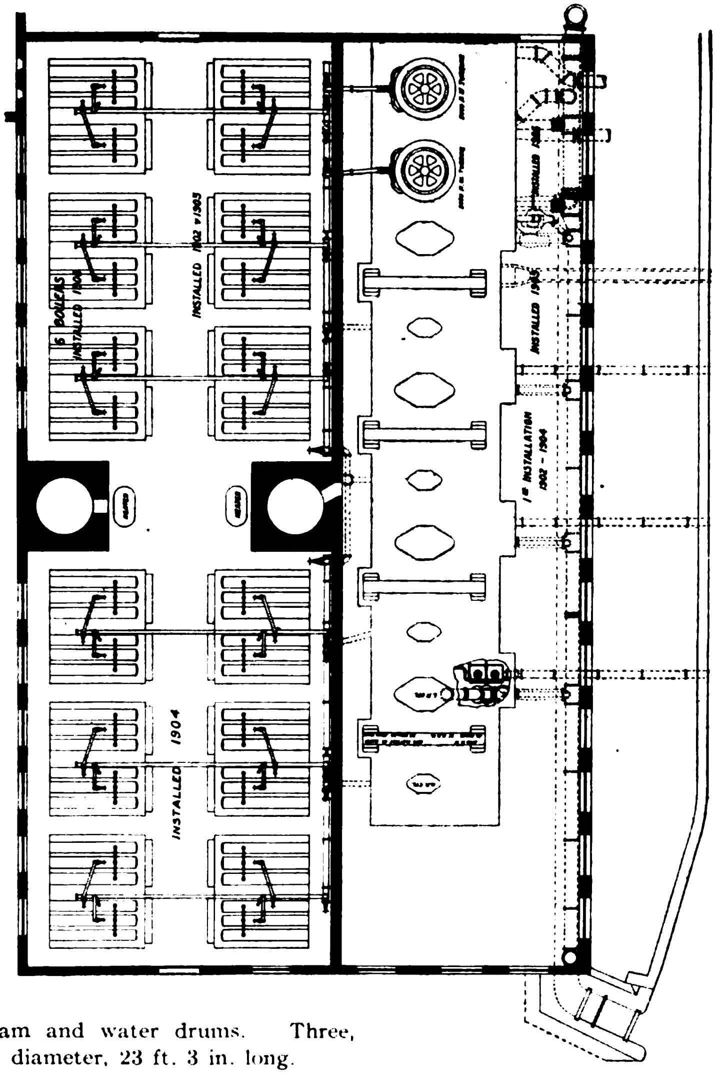
Floor space per battery, 28 ft. 5 in. by 31 ft.; approximate height, 20 ft. 4 in.

SERVICE PUMPS, 2.

Horizontal, duplex, double acting.

Nominal capacity. 1200 gal. each at 45 strokes per min.

Diameter. Steam cylinder, 12 in.; water cylinder, 16 in.; stroke, 18 in.



Plan of Main Steam Connections.

Guaranteed to operate with steam pressure 175 lb.; 75° fahr. superheat; water pressure, 40 lb.

Automatic governor.

Pressure gauge. 10 in. Crosby.

Floor space. 30 in. by 103 in.; approximate height, 50 in.

Weight. Total, 7500 lb.

Service. Deliver clear water from filter to feed-water heaters and building service lines.

SERVICE PUMPS, 2.

Type. Horizontal simplex, low pressure.

Size. Steam cylinder 12 in. by 18 in. water cylinder 18 in. by 18 in.

Pressure Gauge. 10 in. Crosby.

Capacity. 600 gal. each, at 30 strokes per minute.

Suction, 12 ft.; delivery pressure, 20 lb.; maximum temperature water, 110° fahr.

Service. Deliver water from hot-well or river to filter plant.

FEED-WATER HEATERS, 2.

Open type, made of cast iron.

Guaranteed to heat 350,000 lb. of water each, from 60° fahr. to 210° fahr., with steam at atmospheric pressure.

Filtering and settling chamber.

Thermometers. In iron case.

Pressure gauge. 10 in. Ashcroft.

Floor space. 11 ft. 6 in. by 6 ft. 7 in.; approximate height, 16 ft. 4 in.

Weight. Total, 60,000 lb.

Steam inlet. 12 in.; outlet, 8 in.

Water inlet. 8 in., with regulating valve; outlet, 10 in.

BOILER FEED PUMPS, 4.

Type. Marine, vertical, double acting, twin.

Size. Steam cylinder, 14 in. by 24 in.; water cylinder, 10 in. by 24 in.

Floor Space. 84 in. by 48 in. per pair approximate height, 128 in.; weight, 9800 lb. per pair.

Pressure gauge. 10 in. Crosby.

Nominal capacity. 300 gal. each, at 40 strokes per min., with steam at 175 lb. pressure, 75° superheat, against a water pressure of 180 lb.

BOILER FEED-PUMPS, 2.

Type. Admiralty pattern, pot valve, vertical duplex.

Size. Steam cylinder, 18 in. by 18 in.; water cylinder, 12 in. by 18 in.

Nominal capacity. 600 gal, each, at 35 strokes per min, Water temperature 210° fahr. against boiler pressure of 200 lb.

FEED-WATER PIPING.

Two independent headers from each pair of feed-pumps, with cross-connections to corresponding header of other pairs of pumps.

Boiler connection. From each header system to each boiler.

Pump connection. Which allows for a supply of either hot or cold water to each header system.

LIVE-STEAM PIPING.

Wrought iron; welded steam flange semi-steel fittings; high-pressure valves with by-passes on all above 8 in. diameter.

Main header. 16 in. diameter, in two sections, connected by 14 in. loop with cut-off valves at each end; cut-off valves in header providing for operating independently one engine with four boilers.

Auxiliary header. 8 in. diameter, with connections to service pumps, air-pumps, and exciter.

Boiler connection. One to each four boilers; 12 in. diameter; 8 ft. radius, 90° sweep to first battery; 10 in. diameter to second battery; 7 in. diameter, 3 ft. 3 in. radius, 180° sweep to each boiler; two cut-off valves for each boiler and one at header.

Engine connection. 14 in. diameter, 6 ft. radius, 90° sweep; 16 in. separator supported on springs; trap; 4 in. auxiliary outlet; cut-off valve at header.

Turbine connection. 12 in. diameter, 6 ft. 6 in. radius, 180° sweep. Cut-off valve at header. Gaskets, asbestos center, and double copper jacket.

Exciter connection. 4 in. diameter

from main header; 4 in. separator; 3 in. diameter extension to service-pump; auxiliary 3 in. diameter connection to separator of one engine.

Exhaust Piping.

Cast iron and riveted sheet-steel with cast flanges; copper U-shaped expansion joints.

Main engine. 34 in. diameter to 30 in. relief valve; 36 in. connection to condenser; 30 in. connection to header.

Turbine. 30 in. relief valve; 30 in. connection to header.

Main header. With free exhaust to atmosphere at each end of engine-room. West end 42 in., east end 54 in. galvanized exhaust heads.

Auxiliary header. 12 in. diameter connection to heaters; 5 in. diameter free exhaust to roof with 5 in. galvanized head.

Condenser engines exhaust into heater or low-pressure receiver of engines; feed-water pumps, into heater; stoker engines, under grates.

Pipe Covering.

Live steam piping. Two layers, each 1½ in. thick.

Exhaust and hot water piping. One layer, 1½ in. thick.

Material used. 85 per cent. carbonated magnesia, moulded blocks; with outside layer on live steam piping 1.5 in. thick, of cork and asbestos felt.

Finish. Each layer covered with canvas, pasted on entire covering; joints lapped; flanges and bolts exposed. Painted with two coats of lead paint.

Main Engines, 4.

Vertical cross-compound condensing engines without fly-wheel.

Nominal capacity. 5000 i.h.p., with steam consumption of 11½ lb. per h.p. hr., with steam at 175 lb. gauge pressure and 75° fahr. superheat, exhausting at 26 in. vacuum at 74¼ rev. per min.

Overload capacity. Of 9000 i.h.p., under similar conditions of pressure and vacuum, at 73 rev. per min.

Diameter of high-pressure cylinder, 46 in.; low-pressure cylinder, 94 in.

Stroke. 60 in.

Regulate between 76 rev. per min. at no load and 73 rev. per min. at 9000 h.p., with variation of not over 0.09 of 1 degree from mean speed. Revolving field of generator equivalent to fly-wheel weight of 308,000 lb., at radius of gyration of 12.2 ft.

Cylinders. Built up in sections, with all valves in the heads.

Valve-gear. Reynolds-Corliss, with automatic weighted governor operating both high-and low-pressure sides. Steam and exhaust valves operated by separate eccentrics. Motor-operated speed control from switchboard.

Safety butterfly valve, operated by independent governor.

Pressure gauges. One steam gauge, one receiver gauge, one vacuum gauge.

Floor space. Of 17 ft. by 36 ft.; approximate height, 36 ft.

Journal. Main, 30 in. by 60 in.; cross head pins, 14 in. by 14 in.; crank-pins, 14 in. by 14 in.

Shaft. 33 in. diameter at hub of revolving field. Hollow forged of bessemer fluid-compressed steel. Inside diameter, 14 in.

Condensers, 3 (Engines 1, 2, 3).

Jet. Vertical; twin, beam-connected; double-acting steam; single-acting air.

Diameter. Steam cylinder, 18 in.; water cylinder, 48 in.

Stroke. 24 in.

Guaranteed to operate with a steam pressure of 175 lb. and against exhaust pressure 40 lb.

Floor space. 9 ft. by 11 ft.; approximate height, 15 ft.

Valves. Of rubber, 5 in. diameter; valve decks of bronze.

Safety automatic vacuum brake and 5 in. priming inlet.

Condenser, 1 (Engine 4).

Barometric type. Condenser chamber attached to engine cylinder.

Barometric columns. One 16 in. for

removal of both air and water; one 20 in. for overflow.

Injectors. 20 in.

Centrifugal pump. Driven by Ball engine.

Relief valve. 30 in. open air. 30 in. free exhaust to header, ⅛ in. steel-riveted pipe.

Guaranteed to maintain 26 in. vacuum when condensing 140,000 lb. steam per hr., with injection water of 70° fahr.

Engine Generators, 4.

Alternating current. Three-phase revolving field; fly-wheel type; engine-driven.

Nominal capacity. 3500 kw.; 153 amperes, at 75 rev. per min.

Guaranteed to operate at full load, 100% power-factor, for 24 hr., with 35° cent. rise above room temperature of 25°; 1¼ load, 8 hr., 50° cent.; 1½ load, 1 hr., 42.5° cent.

Efficiency. At 1½ load 96%; full load, 95.5%; ¾ load, 94.5%; ½ load, 92.5%; ¼ load, 88%.

Regulation. 12% of full-load voltage.

Armature winding. Formed coils; Y-connected.

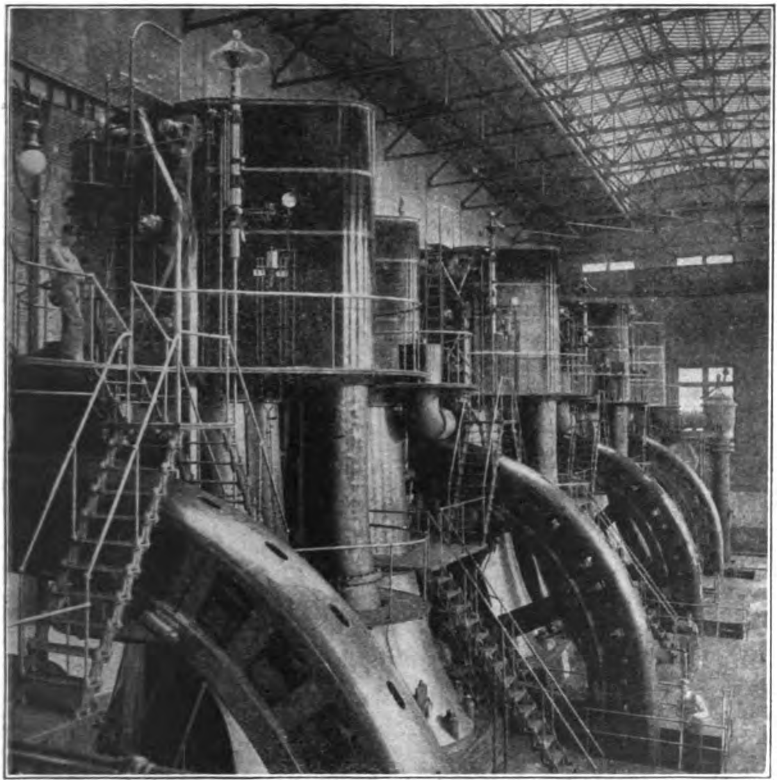
Air-gap. ⅜ in.; number of poles, 56.

Excitation. 125 volts; full load, 100% power-factor, 23 kw.; 150% full load, 50 kw.

Insulation test. Field, 1500 volts alternating-current; armature, 26,200 volts alternating current for one minute.

Floor space. 8 ft. by 34 ft.; approximate height, 34 ft.

Weight. Total, 480,000 lb.; revolving field and shaft, 308,000 lb.; armature,



Engine Room.

157,000 lb.; base and foundation plates, 15,000 lb.

TURBINE UNITS, 2.

Turbines. Curtis type, 5000 kw., 700 rev. per min., 5-stage, form H-11, mounted on base condenser.

Steam consumption. Per kilowatt-hour guaranteed at 175 lb. pressure, 2 in. absolute back pressure, 100° fahr. superheat, ½ load, 18.3 lb.; full load, 17 lb.; 1½ load, 17.5 lb.; variable between ½ and 1½ load, 17.8 lb.

Speed variations, no load to full load, guaranteed not to exceed 2%. Sudden variation in load may cause 4% momentary variation.

Diameter of Base. 15 ft. 2 in.

Runners. Pitch diameter, 11 ft. 6 in.

Pressure gauges. Boiler pressure, pressure at entrance to first stage, vacuum, step bearing hydraulic pressure.

Step bearing. 12 gal. of oil per min. at a pressure of 550 lb. per sq. in.

Governor. Centrifugal, operating valves mechanically.

Generator. 35-cycle, three-phase, 6-pole, 5000 kw., 700 rev. per min., 13,200 volts, 219 amperes per phase, delta-connected.

Temperature rise above 25° cent. guaranteed not to exceed for full load, 24 hr., 40° cent.; 1½ load, 2 hours, 55° cent. Unit to carry 100% overload applied momentarily without injury.

Regulation full load to no load, 8%, speed and excitation remaining constant.

Excitation. 125 volts, 38 kw. maximum, will excite machine at 80% power-factor and given overload in current.

Insulation tests. Alternating current for one minute, armature, 23,200 volts; field, 1500 volts.

Net weight of unit 525,000 lb., height, 29 ft.

CONDENSERS, 2 (TURBINES).

Type. Base, 20,000 sq. ft. of surface in approximately 5000 No. 18 B. W. gauge brass tubes, 1 in. outside diameter.

Capacity. 130,000 lb. steam per hr. maximum, with condensing water at 70° fahr.

Connections. 36 in. cold-water inlet; 36 in. overflow; 12 in. vacuum suction; 6 in. hot-water suction; 30 in. atmospheric exhaust through 30 in. relief valve.

Foundation. Concrete.

TURBINE CONDENSER AUXILIARIES, 2 SETS.

Engine. 4-valve Corliss, 19 in. by 24 in.; fixed cut-off hand adjustment, speed 150 rev. per min. maximum, adjustable to 100 rev. per min.; operating on 175 lb. steam pressure, 150° fahr. superheat, exhausting into feed-water heater.

Dry vacuum pump. Direct connected to engine; 20 in. by 24 in. vertical cylinder; fitted with air-valve gear controlling the three constant points in the compression cycle; namely, opening of the suction, closing of the suction, and closing of the discharge. Vacuum cylinder, water-jacketed. Guaranteed, when shut off from condenser to maintain a vacuum within ½ in. of absolute zero pressure. Fitted with absolute mercurial gauge.

Circulating pump. 30 in. special, volute centrifugal, direct-connected to engine shafts with flexible coupling. Speed 125 rev. per min. Enclosed type impeller, water pumped 18,000 gal. per min. maximum; water level, normal, 5 ft. below basement floor; lowest, 12 ft. below floor. Level on discharge side 4 ft. below basement floor.

Wet vacuum pump. Horizontal 4 in. 2-stage, turbine centrifugal pump direct-connected with flexible coupling to 20 h.p., 550-volt, direct-current motor. Enclosed impeller construction arranged to eliminate all end-thrust. Maximum capacity 300 gal. per min. lifted from bottom of condenser to feed-water heater 51 ft. above basement floor.

Thermometers. One on circulation water inlet; one on circulation water outlet; one in body of condenser.

Hydraulic Accumulator. 1.

Ram. 8 in. diameter, 8 ft. stroke; with positive stop; brass gland.

Weighted to give 550 lb. per sq. in. pressure.

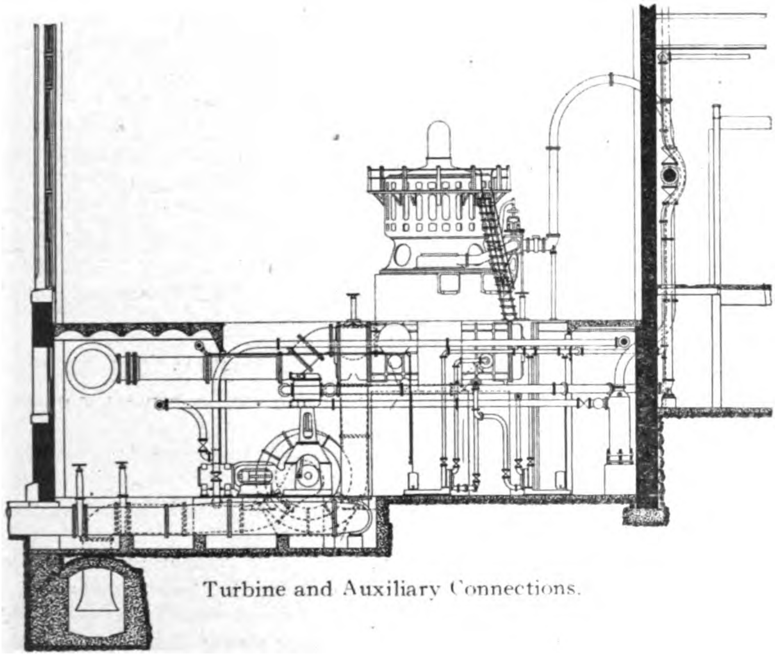
Designed for working pressure of 1200 lb.

Controlling device. Automatic.

Oiling System for Turbines.

High-pressure system. 550 lb. per sq. in.; supplies oil to step-bearing.

Steam pumps. Two, twin; steam cylinder, 7½ in. by 6 in.; oil cylinder, 2 in. by 6 in. These pumps are connected in relay so that if one fails to maintain the required pressure the second will start.



Turbine and Auxiliary Connections.

Electric pump. One, triplex; starts automatically if accumulator falls below predetermined height.

Discharge from step-bearing and governors flows into closed settling tanks. Pumps draw direct from these tanks.

Bleeder removes water and sediment from bottom of tanks to filter.

Low-pressure pump supplies oil for governors, steady bearings, auxiliaries and general lubrication, at 80 lb. pressure.

Filters. One.

Engine-Driven Exciter, 1.

Engine. 11 in. by 11 in.; 280 rev. per min. Vertical, single cylinder type. Piston valve and automatic fly-wheel governor. Steam pressure, 175 lb.; exhaust against 45 lb. pressure.

Generator. 50 kw., 6-pole, shunt-wound, direct-current generator. Full load, 400 amperes, 125 volts; commercial efficiency, full load, 90%. Insulation test, 1500 volts for one minute.

Floor space of set, 98 in. by 55 in.; height, 99 in.

Weight of set, complete, 15,200 lb.

MOTOR-DRIVEN EXCITER SETS, 2.

Transformers. Three, one-phase, 100 kw., 13,200 to 460 volts, 35 cycle; air-blast, ⅜ ounce pressure.

Blower. For transformer ventilation, 700 rev. per min.; operated by a 1 h.p. 6-pole, three-phase induction motor.

Induction motor. 300 h.p.; 520 rev. per min.; 440 volts; 34⅔ cycles.

Insulation test; 2000 volts alternating current for one minute.

Full load efficiency; 92% on 100% power-factor.

Direct-current generator. 200-kw., 8-pole, shunt wound, 520 rev. per min. Full load, 1500 amperes; 125 volts.

Commercial efficiency, 1½ load, 91.5% 1¼ load, 91.5%; full load, 91.5%; ¾ load, 90.5%; ½ load, 87½%; ¼ load, 82%. Insulation test, 1500 volts alternating-current for one minute.

Weight. Total of motor-generator set, 52,000 lb.

CRANE.

Serves engine-room.

Type. Four-motor electric.

Capacity. Main hoist, 80,000 lb.; auxiliary hoist, 10,000 lb.; tested to 25% overload.

Span. 65 ft.

Lift. 60 ft. vertical.

Bridge. Two-girder, double web.

Hoisting Rope. Steel wire.

Net Weight. 105,000 lb.

Speed. With maximum rated load in feet per minute, main hoist, 8 ft., 35 h.p. required; auxiliary hoist, 15 ft., 7½ h.p.; bridge travel, 175 ft., 30 h.p.; trolley travel, 75 ft., 5 h.p. Speed without load, main hoist, 16 ft. per min.; auxiliary hoist, 30 ft.; bridge travel, 200 ft.; trolley travel, 100 ft.

Motors guaranteed to carry full rated load for 15 min. continuously; 25% overload for 3 min.

GENERAL SYSTEM OF HIGH-TENSION CONNECTIONS.

Current from generator at 13,200 volts is conveyed by three-phase cable to generator oil-switch, to disconnecting-switches, to bus-bars.

Bus-bars are divided into three sections by means of oil-switches.

All incoming and outgoing lines are three-phase cables.

Current from incoming lines from water-power station is conveyed through disconnecting-switches, oil-switches and disconnecting-switches in order. The four lines from water-power station connect, two on one bus-bar section, one on each of the others.

Current to outgoing lines is conveyed from bus-bars through disconnecting-switches, oil-switch and disconnecting-switches in order.

In case two or three cables supply a sub-station, they are connected on different sections of the bus-bars.

Static arresters are installed on outgoing and incoming lines to relieve any heavy electrical strains.

Static ground detectors on bus-bar.

Any piece of high-tension apparatus can be disconnected in order to make repairs, or for inspection and cleaning.

STATION SWITCHBOARD.

One exciter generator panel, 50 kw. 125 volt.

Two exciter generator panels, 200 kw. 125 volt.

Two induction motor panels, 300 h.p. 13,200 volts.

Four alternating-current generator panels, 3500 kw. 13,200 volts.

Two alternating-current turbine generator panels, 5000 kw. 13,200 volts.

Twelve alternating-current outgoing line panels, 4500 kw., 13,200 volts.

Four alternating-current incoming line panels, 1650 kw. 13,200 volts.

One synchronizer.

One Tirrill regulator and bus-tieing panel.

All panels are blue Vermont marble and instruments have marine finish.

A 55-cell storage-battery is installed for operating oil-switches.

Generator and line panels are equipped with polyphase integrating wattmeters

Establishment of a Historical Museum

The attention of all members and friends of the Institute is called to the following resolutions passed by the Board of Directors at its meeting of January 25, 1907:

"*Resolved*, That the Library Committee is hereby authorized to accept on behalf of the Institute, donations of original appparatus, models, photographs, manuscripts, printed documents and similar exhibits suitable for a museum of historical electrical material; also to accept the loan of material of the same general character which cannot be secured by gift.

"*Resolved*, That each donation or loan accepted under the foregoing resolution shall be acknowledged by the Chairman of the Library Committee, specifying the articles received in sufficient detail to ensure subsequent identification, and reciting the conditions of gift or loan and acceptance."

The desirability of such a department of the Institute work, permanently in charge of the standing committee which under the Constitution is responsible for all the property of the Institute, has been for some years appreciated by a few of those old-time members who are able to say, regarding the last thirty years' phenomenal growth of several branches of the electrical arts, "all of which I saw and part of which I was." Such men will welcome the adoption of a definite policy of utilizing a portion of the new fire-proof home of the engineering societies, as a secure center in which may be gathered and preserved some of those "first things" in electrical apparatus, pictures and manuscripts which have not already been destroyed by wear and tear, or by committal to the scrap-heap, or by fire. Undoubtedly the younger members will recognize quickly the educational value of the first exhibits, and soon become active in rescuing from destruction the comparatively few early models and documents which can at this somewhat late day be found intact or useful in some degree from an educational standpoint.

Thus the Museum should and may become tributary to the great Engineering Library which is hereafter to constitute so important a feature of the forces radiating from the new home of the fraternity. In fact, a properly organized Museum may be said to merge insensibly into an affiliated Library through the records, and especially the drawings and manuscripts which in an important sense are common to both.

The first effective effort in this direction was made by Past-president Wheeler shortly before his retirement from office last year, by enlisting the sympathetic coöperation of Mr. Edward D. Adams and then securing the adoption by the Board of Directors, of a general resolution which led to the later and more specific expression above quoted.

The Library Committee now invites correspondence regarding original relics, of the general character specified by the resolutions, which can be identified as genuine and having a well-authenticated history. It is not desired to secure models or papers simply because they are old. To adopt such a course would evidently result principally in establishing an electrical junk-shop. The purpose is to place the Museum at the outset on a high plane of excellence, by judicious selection of available material even though the collection grow slowly; by the exercise of special diligence in gathering and displaying information as to the detail of history which each exhibit represents; and by the provision of adequate protection during many years to come for each accepted article. Thus the conditions of security, permanency, and accessibility which invite contributions to the Library will equally encourage similar donations to the Museum.

It is especially desirable that a number of exhibits sufficient to constitute a substantial nucleus should be gathered during the month of March, to afford a concrete illustration of the Museum idea and particularly of the methods proposed in permanently displaying the exhibits. Such a nucleus should attract the attention and secure the confidence of all members and friends who may visit the Engineering Societies building during the dedicatory exercises in April, or read the published accounts of these festivities, and thus get their first specific impressions of the purposes of the Institute in dedicating definite space to relics of the early days of electrical development; as well as of the facilities which are to be offered for observation and study of such relics in time to come.

Each article or group accepted will bear the name of the donor, and a careful registry will be kept of the conditions, if any, under which it has been contributed; to the end that the wishes of the donor regarding it may be kept in mind and respected by the Institute, in general accordance with the methods pursued in the case of articles donated to other corporate bodies, such as to the Metropolitan Museum of Art.

It is to be hoped that the affiliated societies, the mechanical and mining engineers, will also encourage similar collections in their respective fields, and eventually become associated with the Institute in maintaining a great Engineering Museum on the general plan above outlined.

As a result of many years' experience in the preservation of original apparatus, models, photographs, and documents of all descriptions, such as will be of great importance in the eventual writing of electrical history after legal issues as to individual rights shall have been settled and faded into obscurity, several of the members of the Committee are deeply interested in the inception and success of this Museum. It is hoped this may prove a fortunate circumstance.

W. J. JENKS,
Chairman of the Library Committee,
120 Broadway, New York.

Local Organizations

UNIVERSITY OF ARKANSAS

At a meeting of this Branch in the Engineers' Hall on February 6, 1907, attended by eighteen members and visitors, a general discussion was held on the Institute paper entitled "On the Substitution of the Electric Motor for the Steam Locomotive." Professor Olney then delivered a lecture on "Electroplating," illustrating his subject by nickelplating various metallic articles submitted by the audience.

UNIVERSITY OF COLORADO

Owing to the graduation in 1906 of Secretary Forbess, this Branch has remained inactive during the greater part of the last year. At a recent meeting of the Students of the Institute, called to consider the reviving of the Branch, twelve regular Branch members and thirty so-called associate Branch members responded. Mr. J. N. Kellogg was elected chairman, and Mr. A. C. Streamer, secretary. Meetings are scheduled to be held on the first and third Wednesdays of every month.

At the first meeting held this year, on January 16, Mr. H. G. Glaze of Denver lectured on the "Mercury Arc Rectifier," illustrating his remarks by operating the rectifier owned by the electrical department of the University.

CORNELL UNIVERSITY

The regular monthly meeting of the Cornell University Branch was held in Franklin Hall on the evening of Feb. 8. The paper by Messrs. Stillwell and Putnam on "The Substitution of Electric Motors for the Steam Locomotive" was abstracted and discussed. Messrs. R. L. Stone, W. C. Kennedy, W. H. Balcke, and W. G. Taylor presented the four sections of the paper respectively. Through the courtesy of the New York office the Branch had the benefit of the discussion at New York, and this was abstracted by Professor G. S. Macomber. After a general discussion, Professor H. Wade Hibbard, head of the Railway Mechanical Engineering Department of Sibley College, presented the subject from the steam engineer's standpoint.

The interest in the meeting was intense as was shown by the large attendance, numbering 214. A business meeting preceded the presentation of the paper and the matter of the wearing of a badge by enrolled students was discussed. By an almost unanimous vote it was decided that the Cornell Branch does not favor the wearing of a badge by enrolled students. Another important item of business was the election of a student associate to the local executive committee. It was the desire of the executive committee to have the enrolled students officially recognized, and they were asked to select from among the associates a person who could properly present their interests at meetings of the executive committee.

The local branch continues to grow at a healthful rate and now numbers approximately 110 members, associates and students. It occupies a well established position in the community and meets a definite need. It is as much social as technical.

At the next meeting which will be held on March 1, it is expected that Mr. J. S. Codman of the Schenectady Branch will present a paper on the general topic "Charging for Electricity." Mr. Codman will give the Branch the benefit of his experience on maximum demand indicators and allied subjects.

University of Illinois

Fifty-eight members and visitors attended a meeting of this Branch in the electrical engineering laboratory on Feb. 12, 1907. The business of the meeting was as follows:

Special Branch business, relative to methods of increasing the Branch membership.

An original paper entitled "Induction Motors in Concatenation," prepared from the thesis of Mr. Hollister and R. O. Friend, of the University, was presented by Mr. Hollister.

The Institute paper entitled, "On the Substitution of the Electric Motor for the Steam Locomotive," was abstracted by Professor E. C. Schmidt of the railway engineering department.

The meetings here are fairly well attended, by men interested in the papers under discussion. Everything looks toward an increasing interest as well as an increasing number of members.

University of Missouri

At a meeting of this Branch, on Jan. 18, 1907, fourteen members and visitors discussed the Institute paper entitled, "Recent Investigation of Lightning Protective Apparatus."

Ohio State University

Four meetings were held by this Branch during the fall term, notices of which, however, have failed to reach the Secretary's office. At one of these meetings the following were elected officers of the Branch: C. R. Beall, chairman; A. R. Knight, secretary; F. C. Caldwell, corresponding secretary.

At a meeting held January 28, eighteen members and visitors discussed an original paper entitled. "Insulation," presented by E. S. Zuck. Mr. A. D. Cranston read President Sheldon's inaugural address on "The Work of the Institute."

Philadelphia

Sixty-five members and officers attended a meeting of this Branch at the Engineers' Club, Feb. 11, 1907. The following papers were presented and discussed:

"Automatic Electric Block Signals on Electric Railways," by Mr. A. Parker-Smith of the Eureka Automatic Electric Signal Company.

"Electric Block Signals on Electric Railways Operating under Steam Road Conditions," by Mr. L. F. Howard, of the Union Switch and Signal Company.

"Herrick Bond-Testing Car," by Mr. H. S. Murphy.

The papers were illustrated with

lantern-slides and apparatus in operation.

PITTSBURG

The regular monthly meeting of the Pittsburg Branch was held at Carnegie Technical Schools, on Feb. 12, 1907. One hundred and twenty-five members and visitors listened to an abstract of the Institute paper entitled, "On the Substitution of the Electric Motor for the Steam Locomotive," by Mr. McLaren. Mr. McLaren placed it before the meeting in a very satisfactory manner in about twenty minutes.

Mr. P. M. Lincoln discussed this paper from standpoint of power transmission, explaining the different methods of electrical application and the relative costs of transmitting the energy by these different systems, and the advantages of the one-phase current over that of direct-current or polyphase alternating current.

Mr. N. W. Storer discussed the electric locomotive, pointing out the large number of steam locomotives now in use, and the present small capacity in this country for turning out electric locomotives. Mr. Storer also called attention to the advisability of using 15-cycle one-phase current for operating these locomotives. He briefly discussed the use of polyphase motors, especially emphasizing the trouble which would be experienced if the car wheels to which these motors are attached were not of exactly the same diameter. The small difference in slip of these motors due to variation in size of car-wheel would severely overload some motors, and perhaps cause others to operate as generators.

Mr. Wm. Cooper discussed the multiple-control system, pointing out the fact that the present steam locomotives require six to seven minutes to obtain speed of 60 miles per hour, whereas the brake used on a railway train brought the train to rest in twenty seconds. He called attention to the fact that the electric locomotive would be able to accelerate the train in less than a minute. Mr. Cooper enumerated a great variety of railway controllers now on the market, also the diversity of systems of control, and stated that there had been a lack of standardization in control apparatus, whereas the motors for direct-current work had been fairly well standardized.

He also pointed out possibilities of automatic signaling and general protection of trains operated by electric locomotives, among other things being the automatic application of the air brakes.

PURDUE UNIVERSITY

At a meeting of this Branch held January 15, 1907, ninety-five members and visitors discussed the Institute paper entitled, "New Types of Incandescent Lamps." This meeting was under the direction of Professor C. P. Matthews.

On Jan. 29, Mr. A. E. Dobbs, editor of the *Telephone World*, gave an interesting lecture to a large audience of members and visitors on the subject of "Lightning, its Peculiarities, and Methods of Protection."

At another meeting of this Branch, held Feb. 5, under the head of "Executive Business," the report of the Committee on a Student Pin was read and accepted. The Branch voted to secure two pages of the 1907 "Debris" for Branch purposes. Mr. C. E. Hansell presented an original paper entitled, "Design of a Hydroelectric Plant."

SCHENECTADY

At the regular weekly meeting of the Schenectady Branch, held Jan. 31, 1907, Ernst J. Berg of the General Electric Company read a paper on "Line Constants and Abnormal Voltages and Currents in High-Potential Transmissions." This was the second in a series of lectures which Mr. Berg is giving before the Branch on the generation, transmission, transformation, and application of alternating currents. The speaker abstracted the text and supplemented it with explanations of the derivation and use of the formulas and their application to practical problems. Printed copies of the paper, which dealt with the subject mathematically, were distributed among the members.

Among those who discussed the paper were Messrs. Steinmetz, Eveleth, Creighton, Alexanderson, Summerhayes, and Du Bois, and many interesting reminiscences of experiences with high-tension lines were recounted.

[This paper will be printed in a future number of the PROCEEDINGS.]

SEATTLE

Sixteen members and visitors attended a meeting of this Branch, held Jan. 8, 1907.

A report of committee on revision of Constitution was made by chairman C. E. Magnusson and accepted.

The Branch voted to hold regular monthly meetings on the third Saturday instead of the second Tuesday of every month.

The following officers were elected for ensuing year: C. E. Magnusson, chairman; W. S. Wheeler, secretary; S. C. Lindsay, E. G. Allen, John Harisberger, executive committee.

In order to accommodate out-of-town members who spend their Sundays in Seattle, the Branch will hold its regular monthly meeting on the third Saturday of every month instead of the second Tuesday as heretofore. These members will thus be able to attend the regular meeting without making an extra trip, by coming in on Saturday evening to attend the meeting and then staying over Sunday.

Steps are being taken by the Branch to invite the Institute to hold the annual convention in Seattle during the Alaska-Yukon-Pacific Fair in the summer of the year 1909. The secretary of the Branch has been instructed to correspond with Secretary Ralph W. Pope and find out if the Institute is in a position to consider this favorably.

Although this fair will not be as large as the World's Fair at St. Louis in the year 1904, it will certainly be much larger than the Lewis and Clark Exposition held in Portland, Oregon, during the summer of 1905.

The discussion of "Lightning Protective Apparatus" at the last meeting of the Branch brought out the fact that choke-coils in high-tension transmission should be done away with as much as possible, and the first coil of the transformer should have an extra thickness of insulation, as it is this coil that invariably punctures first during lightning discharges and surges in the system.

Mr. Don Middleton of the Independent Telephone Co. left Jan. 19, 1907, for the Dakotas, where he will have charge of installing automatic telephone exchanges until next summer, when we expect to have him with us again.

Mr. O. R. Cole of the Sunset Telephone and Telegraph Co. has left Seattle and is now located permanently in California, forwarding the Bell interests.

SYRACUSE UNIVERSITY

At the regular meeting of this Branch, held in the Smith College of Applied Science, Syracuse University, on Jan. 17, Mr. C. A. Call, '07, gave an abstract from the December PROCEEDINGS on "Recent Investigation of Lightning Protective Apparatus." Mr. H. A. Yoe, '07, presented a paper on "Wireless Telegraphy." An interesting discussion followed the reading of each paper.

Plans are being made by this Branch to visit the Baldwin Locomotive Works and the works of the General Electric Company, at Schenectady, N. Y., in the near future.

Another meeting of this Branch was held Feb. 7, at which twenty-nine members and visitors were present. Mr. A. B. Bond, electrical engineer of the Niagara, Lockport, and Ontario Power Company, talked on the subject of "Methods of Financing Electric Properties."

TORONTO

On Nov. 9, 1906, fifty-one members and visitors attended a meeting of this Branch, at which Mr. Corlis G. Keyes read a paper entitled, "The Nernst Lamp," written by Mr. A. E. Fleming, of Hamilton, who was unavoidably absent. Discussion on this paper was participated in by Messrs. Bucke, Conried, Aitken, Kitchen, Lambe, Andrew, Park, Chase, and Pratt.

Thirty members and visitors attended a meeting of this Branch held at the Engineers' Club, Toronto, on Jan. 17, 1907.

Mr. A. B. Lambe read an extract of Mr. Alex Dow's paper on "Direct Current Distribution," which was read before the Electrical Congress at St. Louis, and Mr. K. L. Aitken abstracted Mr. Barnes' paper which was read before the National Electric Light Association, describing the 250–500 volt system as used by the Narragansett Power Co. of Providence, R. I.

The papers were very interesting, and provoked a good deal of discussion, which was taken part in by Cecil B. Smith, R. G. Black, S. W. Smith, E. W. Sothmann, W. A. Bucke, H. F. Strickland, K. L. Aitken, E. Richards, L. W. Pratt.

At a meeting held Feb. 8, 1907, Mr. C. H. Mitchell, gave an address on European Hydroelectric Power Plants, illustrated by a large number of dissolving views.

WASHINGTON

The first meeting of the Washington Branch for the year 1906–1907 was held at the George Washington University on October 19, 1906. Thirty-six members and visitors being present.

The chairman announced that there would be eight meetings during the season, each to be in charge of some specialist who would be responsible for the program of the meeting, and an invitation was given to all members to suggest appropriate general subjects.

The subject for this meeting was "Illumination," the paper being read by Mr. J. E. Woodwell, electrical engineer of the Treasury Department. (This paper had been originally delivered before the Society of Illuminating Engineers, on October 12, 1906.) A large number of lantern-slides were used to illustrate the points of interest. The following took part in the discussion C. A. Blatchley, on lighting the Bureau of Engraving and Printing; A. S. Riddle, on lighting the Post Office by Cooper Hewitt lamps; W. C. Allen, on lighting ot new Union Station; Paul Burton, on experiences; Dr. Hyde of the Bureau of Standards, on theoretical consideration; P. Betts, on factory lighting; C. A. Blatchley, on illumination of machinery; J. E. Woodwell on Moore tube lighting.

Another meeting was held at the National Bureau of Standards on Nov. 21, 1906, twenty-three members and visitors attending.

No business was transacted and no papers were presented. Members arrived at 8:00 p.m. and spent the time until 10:00 p.m. in the various laboratories listening to explanations given by those in charge of the respective sections of the work. At 10:00 p.m. all adjourned to the refectory on the fourth floor of the main building, where a collation was served.

A vote of thanks was extended to Director Stratton, and his assistants, and final adjournmentwas had at 11:00 p.m.

At another meeting held in the Signal Corps Laboratory, 1744 G Street, on December 19, 1906, twenty-six members and visitors were interested listeners of a description and explanation of the methods of the signal department.

No business was transacted. At 8:30 p.m. Major Russel called the meeting to order and commenced the explanation of the modern fire control system, as employed by the Signal Corps in the protection of harbors, etc. Explanations and exhibitions followed, of the telautograph, signal corps telephone and telegraph systems, wireless telegraph, and other methods of signaling employed by the U. S. army.

After a vote of thanks had been extended to Major Russel and his force of laboratorians, the meeting adjourned at 10:45 p.m.

The regular meeting of the Washington Branch of the American Institute of Electrical Engineers was held in the Main Hall of the George Washington University on the evening of Jan. 24. The subject which had been assigned to the meeting was "Telephony," especially the subject of "Telephony in Washington."

Mr. George C. Maynard, electrical director of the Smithsonian Institution, read an exceedingly interesting paper, regarding the early history of the "National Telephonic Exchange," the original licensee under the Bell patents for the District of Columbia, and of which Mr. Maynard was general manager and moving spirit for many years. The paper recited the great difficulty in obtaining fifty people as subscribers to the first telephone exchange, which was finally opened in November, 1876. The instruments used were of three or four types manufactured by as many different individuals, and the switchboard was of the "peg" type generally used in telegraph offices at the time. The growth of the system in Washington from the modest beginning mentioned, until 1883, when it had one thousand subscribers, was detailed, and many incidents of local interest were brought out by the author of the paper.

Mr. P. G. Burton, division superintendent of the Chesapeake and Potomac Telephone Company, took up the thread of the story where Mr. Maynard's paper left it, showing the growth of the system from 1883 until the present time. Mr. Burton's paper was illustrated with lantern-slides, showing many of the old pole lines which filled the streets of the city until a comparatively recent date, and with other photographs showing the underground system of distribution used at the present time. A map was also shown, on which was indicated the existing conduit system of the company with proposed extensions, and also the location of present and proposed exchanges.

Curves were shown, indicating the growth of telephony in Washington, and in the United States, from the earliest days until the present time, and showing that almost half of the total number of subscribers in Washington have been added to the system during the last two years.

An exhibit of especial interest was a section of the first system of underground wires laid in Washington for telephonic purposes, and which consisted of porcelain diaphragms about 3.5 in. by 6 in., which were placed four feet apart in a wooden trough. These diaphragms were pierced with sixty holes, through which were drawn bare and cotton-insulated wires, and the boxes were then filled with tar. The projector of this system had not calculated on the great heat of a Washington summer, for the first difficulty experienced with this system was that of the tar becoming a fluid, and flowing through the diaphragms into the basement of the exchange.

Several pieces of old style cable, both rubber and cotton insulated, were shown, some of which have been buried in the streets since 1883.

There was also shown a section of the so-called "solid system," which consisted of cotton-insulated, saturated-core, lead-covered cable, buried in asphalt, which was for many years the standard system of underground distribution in Washington.

As a contrast to this, pieces of modern 600-pair paper-insulated cable were shown.

The papers were discussed by Messrs. F. H. Bethell, and B. W. Trafford, vice-president and general manager, respectively, of the Chesapeake and Potomac Telephone Company; also by Messrs, E. E. Clement, Colonel Samuel Reber, U.S.A., and others.

EXTRACTS FROM MR. BURTON'S TALK, JANUARY 24, 1907

"It is realized that the manual switchboard and methods of operation have reached a finality, no fundamental changes having been made therein for at least ten years. During these ten years, automatic apparatus and systems of operation have been developed and brought into commercial use on a considerable scale, and although the automatic apparatus thus made available has been admittedly crude from a mechanical standpoint, and has been unable to furnish certain kinds of service, such as four-party selective pay stations, etc., nevertheless it has shown its capability for competing with manual apparatus, and is claimed in many cases to produce good results in the way of economy of operation and maintenance. The change from standard manual equipment to the present type of automatic equipment is too radical to be generally possible. Moreover, if there is any advantage beyond the amusement of some subscribers in having the subscribers do the work of connection, it is not sufficient in the great majority of cases to justify the sacrifice of good manual equipment. From the standpoint of the engineer and the manufacturer, it appears also an unpardonable error even to think of throwing aside all of the standard practice most painfully evolved through thirty years of hard work by some of the most capable men this country has ever known.

The problem of to-day is how to utilize the meritorious features of automatic without sacrificing the good points of the manual practice, and without producing such complete changes as to cause losses out of proportion to the benefits conferred.

The conclusion seems inevitable that the system of the future, even of the immediate future, will involve a combination of manual and automatic methods, affording a maximum of simplicity and therefore economy in the subscriber's apparatus, and a maximum of efficiency with economy at the central station.

After two or three lessons any American can use a foreign telephone. All he has to learn is which end to put to his ear and how to keep two or three springs pressed down all the time he is talking. In England he takes down the entire telephone from the rack and holds it the same as a slide trombone.

In some of the rooms were electric hair curlers. A Cleveland man who wished to call up the adjoining room on the telephone, just to see if the thing would work, put the hair curler to his ear and began talking into the dynamo. There was no response, so he pushed a button and nearly ruined his left ear. It was a natural mistake. In Europe anything attached to a wall is liable to be a telephone.

On the whole, I think our telephone system is superior to that of any foreign cities. In England 'hallo' is never used. When an Englishman gathers up the ponderous contrivance and fits it against his head he asks, 'Are you there'? If the other man answers 'No,' that ends the conversation."

Copy of a Notice Sent Out to the Early Subscribers, Giving Directions for Using Various Styles of Instruments, All of Which Were in Use at the Time

"The word 'halloo' being very easily heard in the telephone, has come into general use to call attention, to ascertain if any one is listening, etc.

"Signals are made in the following manner:

"On the bells with side switches, by simply lifting the hand telephone off from the switch. The telephone must always hang on the switch when not in use.

"On the bells with lower hook switches, by pressing the black button firmly once. The switch must be turned to the left while conversation is being held, and be kept in a perpendicular position at all other times.

"On the bells with the two buttons, by pressing the black button firmly once.

"The black button must be held down during the conversation.

"On the magneto bells; by revolving the crank and making three taps on the button of the lower end of the box."

WASHINGTON UNIVERSITY.

At a meeting of this Branch, held Jan. 2, the following papers were read and discussed:

1. Electrolysis in Street Railway Service, by W. C. Bryan.
2. Wireless Telegraphy, by A. E. Wright.

UNIVERSITY OF WISCONSIN

The interest in Branch work is growing steadily, and our present scheme for arranging the programs is working out very satisfactorily. The plan is to have one of the New York papers abstracted, and an original paper or discussion by a local engineer, at each of the monthly meetings.

The original papers to date have been:

"General Electric Methods of Testing," by Mr. John R. Price, formerly with the General Electric Company and at present on the instructional staff of the University of Wisconsin.

"The Development of a Successful High-Tension Outlet," by Mr. Alvin Meyers, of Provo, Utah. Read in the absence of the author by Professor D. C. Jackson.

"The Electrical Equipment of a Modern Battle Ship," by Mr. R. M. Klein, formerly of the U. S. Navy Department, at present on the engineering staff of the Northern Electric Co.

The attendance has been very good and the discussions show a lively interest in the work.

WORCESTER POLYTECHNIC INSTITUTE

The regular meeting of the Branch was held Monday evening, Feb. 11, 1907, in the Engineering Lecture Room Salisbury Laboratories, with A. P. Chapman, president, as presiding officer. The paper, " On the Substitution of the Electric Motor for the Steam Locomotive," presented before the Institute by Messrs. Stillwell and Putnam, was abstracted by Messrs. Haynes, Stocks and Smith. A discussion of the question followed the presentation of the abstracts.

Minutes of Meeting of the Institute

Meeting of the American Institute of Electrical Engineers, held in the Auditorium of the Engineers' Building, 33 West Thirty-ninth street, New York, Friday, January 25, 1907. President Sheldon called the meeting to order at 8:00 o'clock.

The Secretary announced that at the meeting of the Board of Directors held during the afternoon there were 104 Associates elected, as follows:

ADAMS, ROBERT WINTHROP, Electrical Engineer, D. & W. Fuse Co., 156 Melrose St., Providence, R. I.

ADES, LEWIS HENRY, Testing Laboratory, Chicago Edison Co.; res., 6401 Yale Ave., Chicago, Ill.

ALLARD, ARTHUR, Assistant Engineer Mexican Light and Power Co., Juan Carbonero 48, Mexico City, D. F.

ANDERSON, EMANUEL, Assistant Engineer and Chief Draftsman, Mexican Light & Power Co., Mexico D. F.

ANTHONY, CHARLES CHAPMAN, Inspector of Signals, Pennsylvania R.R., 377 Broad St. Station, Philadelphia, Pa.

AVERILL, REX GILMAN, Technical Writer, Westinghouse Elec. and Mfg. Co., Pittsburg; res., 1000 South Ave., Wilkinsburg, Pa.

BELL, HARRY LAYFIELD, Electrical Engineer, Standard Underground Cable Co., Westinghouse Bldg., Pittsburg.

BENDEKE, CARL, Draftsman, New York Edison Co., New York City; res., 260 President St., Brooklyn, N. Y.

BERRY, EDWARD ROBIE, Chemist, Engineering Laboratory, General Electric Co., Lynn; res., 107 Cross St., Malden, Mass.

BEYER, HENRY, Sales Department, Crocker-Wheeler Co., 1315 North American Bldg., Philadelphia, Pa.

BOLDMAN, CURTIS F., Engineering Apprentice, Westinghouse Elec. and Mfg Co., Pittsburg, Pa.

Boyden, John Hanson, Electrical Patent Expert, Meyers, Cushman and Rea, 510 McGill Bldg., Washington, D. C.

Briggs, Zenas Marston, Railway Engineering Department, General Electric Co., Schenectady, N. Y.

Brockway, Edwin L., General Feeder Foreman N. Y. C. Ry. Co.; res., 213 W. 104th St., New York City.

Brown, Frederic Dill, Superintendent, Twin City Rapid Transit Co.; res., 3711 Nicollet Ave., Minneapolis.

Brown, Walter Throop Kendall, Power and Lighting Engineer, Stanley G. I. Elec. Mfg. Co., Pittsfield, Mass.

Cary, Walter, General Manager, Sawyer-Man Elec. Co., 510 W. 23d St.; res., 16 E. 31st St., New York City.

Chesterman, Francis John, Electrical Engineering Department, American Telephone and Telegraph Co., 125 Milk St., Boston, Mass.

Clarke, William B., Manager, General Electric Co., 1518 Park Bldg., Pittsburg, Pa.

Cohen, Douglas Hart, Engineering Draughtsman, Westinghouse, Church, Kerr & Co.; res., 232 E. 18th St., New York City.

Cohen, Louis, Librarian, Bureau of Standards, Washington, D. C.

Colgan, James Arthur Herbert, Electrical Engineer, Western Electric Co., 463 West St., New York City.

Cordell, William H., General Foreman, New York Edison Co.; res., 548 W. 156th St., New York City.

Cornick, Tully R., Superintendent Transmission Lines, Mexican Light and Power Co., San Jose El Real No. 22, Mexico City, Mex.

Daniels, Raymond Safford, Electrician, Washington Water Power Co., Post Falls, Idaho.

Danielson, Oscar Alvin, Engineer, Western Electric Co., 463 West St.; res., 54 W. 65th St., New York City.

Davenport, John Coolidge, Electrical Engineer, Bullock Electric Mfg. Co.; res., 2257 Monroe Ave., Cincinnati, O.

Dearborn, Richard Harold, Assistant Professor of Electric Engineering, University of Oregon, 341 E. 9th St., Eugene, Ore.

Dellert, Joseph G., Student, Polytechnic Institute; res., 76 St. Marks Ave., Brooklyn, N. Y.

Dewhurst, Richard Miles, Electrical Engineer, Standard Underground Cable Co., Westinghouse Bldg., Pittsburg, Pa.

Dinham-Peran, Arthur Edward Halloran, Electrical Apprentice British Westinghouse Electric and Mfg. Co. Ltd., " Bealings " Southborne-on-Sea Christchurch, Hampshire, Eng.

Dressner, Victor Dorsey, Student, Polytechnic Institute, Brooklyn; res., 202 W. 131st St., New York City.

Dunn, John Franklin, Draughtsman, Westinghouse, Church, Kerr & Co.; res., 400 Manhattan Ave., New York City.

Foley, Hiram Saine, Superintendent, San Ildefonso Division, Mexican Light and Power Co., Mexico City, Mex.

Forde, Bert, Erecting Engineer, Crocker-Wheeler Co.; res., 601 Racine Ave., Chicago, Ill.

Fox, Maurice Edward, Student, Polytechnic Institute, Brooklyn; res., Hewletts, L. I., N. Y.

Gates, William Franklin, Tester, General Electric Co., Schenectady, N. Y.

Gierisch, Otto Tomas, Draughtsman, Brooklyn Heights R.R. Co., 85 Clinton St., Brooklyn; res., 935 E. 137th St., New York City.

Gilbert, Henry Curtis, Jr., Department of Electricity, Jamestown Exposition Co., Pine Beach, Va.

Grosvenor, Graham, Otis Elevator Co. 17 Battery Pl.; res., 126 W. 12th St., New York City.

GULICK, RAYMOND W., Electrical Draftsman, U. S. Navy Yard; res., 44 Fort Greene Pl., Brooklyn, N. Y.

HALL, EDWIN CHAMBERLAYNE, Manager, Gray National Telautograph Co.; res., 4815 Centre Ave., Pittsburg, Pa.

HAMILTON, HUGH DE COURSEY, Sales Engineer, Crocker-Wheeler Co., 1315 North American Bldg., Philadelphia,

HANSSEN, IVAN EIVIND, Electrical Engineer, Stanley G. I. Electric Mfg. Co.; res., 27 Willis St., Pittsfield, Mass

HENRY, ARTHUR SEYMOUR, Construction Department, Western Electric Co.; res., 634 E. 139th St., New York City.

HERR, EDWIN M., First Vice-president Westinghouse Electric and Mfg. Co.; res., 140 Hutchinson Ave., Edgewood Park, Pa.

HOLDEN, SAMUEL SPRAGUE, Student, Polytechnic Institute; res., 237 Quincy St., Brooklyn, N. Y.

HOUGH, ROBERT HARBISON, Instructor in Physics, University of Pennsylvania, Philadelphia, Pa.

JACKSON, CLARENCE CHARLES, Designing Engineer, American Transformer Co.; res., 59 Burnet St., Newark, N. J.

JACKSON, HENRY WHITING, Chief Engineer, Sawyer-Man Electric Co., 510 W. 23d St., New York City; res., 46 So. Maple Ave., E. Orange, N. J.

KEATING, WILLIAM A., Assistant District Superintendent, Allegheny Co. Light Co., 6812 Frankstown Ave., Pittsburg, Pa.

KENYON, MAXWELL S., Chief Assistant Traction Sales, British Westinghouse Co. Ltd., Trafford Park, Manchester, Eng.

KERR, WALTER C., President, Westinghouse, Church, Kerr & Co., 10 Bridge St., New York City; res., Dongan Hills, S. I., N. Y.

KNAPP, MORRIS JASON, 117½ W. Main St., Oklahoma City, Okla.

KUNIYASU, UICHI, Test Man, General Electric Co., Schenectady, N. Y.

LANDON, EDWIN, Instructor in Department of Electricity, School of Submarine Defense, Fort Totten, N. Y.

LOTSPEICH, WILEY WALTER, Constructing Engineer and Superintendent, Marion Light and Power Co., Marion, N. C.

MADGE, REGINALD GEORGE, Power Stations Superintendent, Mexico Light and Power Co.; res., British Club of Mexico, Mexico City, Mex.

DE MAGALHAES, FRANK VASCONCELLOS, Testing Bureau, Brooklyn Rapid Transit Co.; res., 168 State St., Brooklyn, N. Y.

MAGRAW, LESTER ANDREW, Alternating Current Testing, Crocker-Wheeler Co. Ampere; res., 29 N. 17th St., East Orange, N. J.

MANSON, DANIEL EDGAR, Manager, Westinghouse Electric and Mfg. Co., Boston; res., 67 Perry St., Brookline, Mass.

MATHEY, EDWARD DUBOIS, Chief Draughtsman Electrical Department Westinghouse, Church, Kerr & Co., New York City; res., 921 Hudson St., Hoboken, N. J.

MEAD, WILLIAM ALGERNON, Foreman, Harry Alexander Co., 18 W. 34th St.; res., 405 W. 17th St., New York City.

MCKINSTRY, ARCHIBALD, Chief Assistant Plant Department, British Westinghouse Electric and Mfg. Co., Manchester, Eng.

MCMORROW, CHARLES P., Construction Department, Fort Wayne Electric Works; res., 601 W. Washington St., Fort Wayne, Ind.

MOORE, GEORGE HOLMES, Electrical Engineer, Kilbourne and Clark Co., 816 Ferry Ave., Seattle, Wash.

MOORE, WILLIAM WASHINGTON, Manager Engineering Department, Wesco Supply Co.; res., 4122a McPherson Ave., St. Louis, Mo.

MYLER, PAUL JUDSON, Vice-president and General Manager, Canadian Westinghouse Co., Hamilton, Ont.

NESBIT, ARTHUR FLEMING, Professor of Physics and Electrical Engineering, New Hampshire College, Durham, N. H.

NIMS, FREDERICK D., Chief Operating Engineer, Mexican Light and Power Co., Mexico City, D. F., Mex.

NODELL, WILLIAM LEON, Student Polytechnic Institute; res., 243 South 4th St., Brooklyn, N. Y.

OLNEY, WILLIAM MAIRS, Assistant to Division Equipment Engineer, N. Y. and N. J. Telephone Co., 547 Clinton Ave., Brooklyn, N. Y.

OSCHMANN, WILLIAM OLIVER, Erecting Engineer, Allegheny County Light Co.; res., 28 Lombard St., Allegheny, Pa.

PARDEE, HARVEY SABIN, Special Electrical Designing, Tri-State Telephone and Telegraph Co., Minneapolis, Min.

PARKER, RALZEMOND DRAKE, Instructor in Electrical Engineering, University of Michigan, Ann Arbor, Mich.

PETURA, FRANK JOSEPH, Member of Experimental Corps, Denver Gas and Electric Co., Denver, Colo.

PIKE, DANIEL ELVIN, Operator, Western Union Telegraph Co., New York; res., 585 Lafayette Ave., Brooklyn, N. Y.

POTTER, JOHN CHURCH, Instructor in Electrical Engineering, University of Wisconsin, Chemical Engineers' Bldg. Madison, Wis.

RANDALL, JOEL ELMER, Student, Polytechnic Institute; res., 313 Sixth Ave., Brooklyn, N. Y.

REED, LEANDER NELSON, Sales Engineer, Westinghouse Electric and Mfg. Co., Boston; res., 102 Belmont St., Somerville, Mass.

RHODES, C. BORIE, Manager, Willamette Valley Co., Dallas, Ore.

RICHARDS, WALTER JOSEPH, Electrical Engineer, Allis-Chalmers Co., Norwood, O.

ROSS, JOHN OLIVER GORDON, Engineer, Otis Elevator Co.; res., 4 Glenwood Terrace, Yonkers, N. Y.

ROFFEY, MYLES HERBERT, Assistant, British Westinghouse Electric and Mfg. Co., Littlecot, Hornchurch, Essex, Eng.

RUSSELL, FRANK HENRY, President Automatic Hook and Eye Co., Hoboken; res., 131 Sylvan St., Rutherford, N. J.

RUSSELL, SAMUEL, JR., Manager, Crocker-Wheeler Co., 1315 North American Bldg., Philadelphia, Pa.

SCALES, HENRY JACKSON, Electrical Department, American Sheet and Tin Plate Co., Vandergrift, Pa.

SCHEEL, HENRY VAN RIPER, Assistant to General Superintendent, MacAndrews and Forbes Co., Newark, N. J.; res., 970 Park Ave., New York City.

SCHRODER, BERNARD AUGUSTUS, Manager, Crocker-Wheeler Co., Hibernia Bank Bldg., New Orleans, La.

SIDDALL, JOSEPH J., Student, American Telephone and Telegraph Co., 147 East Ave., Pawtucket, R. I.

SIMPSON, GEORGE THOMAS, Consulting Engineer, 604 Pioneer Press Bldg., St. Paul, Minn.

SMALL, WILLIAM TELFORD, Instructor in Electrical Engineering, Purdue University; res., 427 Russell St., W. Lafayette, Ind.

SMOUT, ALAN, District Mains Superintendent, County of London Electrical Supply Co., Ltd., 3 S. Connaught St., Hyde Park Sq., W. London, Eng.

SNYDER, RICHARD ANDREW LEE, Construction Engineer, Central District & Printing Telegraph Co., 1332 Fulton Bldg., Pittsburg, Pa.

STANTON, WILLARD JAMES, General Superintendent, Corn Belt Telephone Co., Waterloo, Ia.

STONE, ROY LYNNE, Student, Cornell University; res., 408 Eddy St., Ithaca, N. Y.

THOMAS, LUCIAN ALVAH, Draughtsman, Westinghouse, Church, Kerr & Co.; res., 2362 7th Ave., New York City.

THOMPSON, WILBUR HAYES, Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; res., 1314 Wood St., Wilkinsburg, Pa.

WALDO, EDWARD HARDENBERGH, Electrical Engineer, Crocker-Wheeler Co., Ampere; res., Maplewood, N. J.

WALLACE, JOHN FINDLEY, Chairman, Board of Directors, Westinghouse, Church, Kerr & Co., 111 Broadway New York City.

WALLACE, WILLIAM MURRAY, Electrical Draftsman, Westinghouse, Church, Kerr & Co., 10 Bridge St.; res., 60 E. 92d St., New York City.

WATT, GEORGE YOUNG, Student, Polytechnic Institute; res., 22 Stuyvesant Ave., Brooklyn, N. Y.

WEBSTER, CHARLES CARLTON, Chief Engineer Pumping Station, Department of Public Works, Schenectady, N. Y.

WILLIAMS, SAMUEL BYRON, JR., Telephone Engineer, Western Electric Co., 259 So. Clinton St., Chicago, Ill.

WORK, WILLIAM ROTH, Instructor in Electrical Practice, Carnegie Technical Schools, Pittsburg, Pa.

WRIGHT, EDWIN CAREW, Electrical Engineer, Allis-Chalmers Co., Cincinnati, Ohio.

YOUNG, FREDERICK VASPASIAN, Electrical Engineer, Bell Telephone Co. of Missouri, 3844 Olive St., St. Louis, Mo

The Secretary further announced that the following Associates were transferred to the grade of Member:

WILLIAM HENRY BRISTOL, Professor of Mathematics and Mechanics, Stevens Institute, Hoboken, N. J.

HENRY ST. CLAIR PUTNAM, Consulting Electrical Engineer, 100 Broadway, New York City.

PRESIDENT SHELDON: It has been previously announced that the Institute would not hold any of its meetings in this building until after its formal dedication on April 16. Inasmuch, however, as the auditoriums were prepared for our reception, it has seemed desirable that we should occupy them in spite of that statement. It is fortunate that the paper at our first meeting in this building should be of such a character that it is eminently proper for us to invite as our guests and welcome here the members of the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Society of Mechanical Engineers, the New York Electrical Society, the New York Railroad Club, and the Transportation Club. A paper of such interest as to bring these wide interests together emphasizes the necessity for a building of this kind, and it is a matter of great satisfaction and pleasure that the necessity which existed has been met by the beneficence of Mr. Carnegie.

The title of the paper of the evening is " On the Substitution of the Electric Motor for the Steam Locomotive," by Lewis B. Stillwell and Henry St. Clair Putnam. Through the able efforts of the Committee on Papers, Mr. H. G. Stott, chairman, the consent to discuss this paper has been obtained from a large number of engineers eminently qualified for this purpose. This embarrassment of riches will necessitate a time-limit of ten minutes being imposed upon those who succeed Mr. Frank J. Sprague, who will begin the discussion.

Library Committee

The Library Committee of the Institute is charged this year with the execution of several important tasks. This will be better understood by examination of the following list of its subcommittees, some of which have been active since the opening of the Institute fiscal year, while others now find their work beginning with the actual removal of the Library to its new home:

1. Purchase of furniture and floor covering for the Institute offices: Edward Caldwell, Frank N. Waterman.

2. Library subscriptions, purchases, and donations: Edward Caldwell, C. A. Terry.

3. Increased Library utility: Professor Charles F. Chandler, C. A. Terry.

4. Historical museum: F. N. Waterman, W. J. Jenks.

The removal of the books and stacks from 95 Liberty Street is now completed, and the Library will be in condition for general use by the time this issue is received by members.

The delivery of office furnishings will be completed before March 1, and the Institute is to be congratulated on the initial equipment which is of elegant and substantial character and appears sufficient to meet the demands of the next few years, and, in some of its features, for the necessities of a long time to come.

The work of bringing the text-books fully up to date is being seriously discussed and should engage the attention of all members who desire to participate in supplying many modern publications which will, when provided, be constantly consulted.

Closely akin to this is the work of devising and putting into practice plans for enabling members at a distance who can not consult the Library in person, to secure many benefits from a liberal equipment and maintenance. This is justly regarded as one of the most vital questions now before the Committee, and a report will be awaited with great interest.

That the essentials of the proposed Historical Museum are clearly appreciated and will be kept before the Institute will appear by reading the letter on this subject printed in another column. If a tangible beginning is to be made before the April ceremonies, the correspondence which the Committee thus invites should be promptly opened with the chairman by each member or friend of the Institute who is able to donate or loan any relic of permanent interest, stating the terms upon which his contribution will be made, and the available sources of accurate information as to its authenticity and importance.

The amount of work already accomplished in these various directions since October 1 has been made possible by the cordial co-operation of Charles L. Clarke, who though not a member of the Library Committee, has acted as its secretary and greatly assisted during the period of removal activity.

About December 1, on the resignation of Miss Bragg, Miss Jessie R. Hammett assumed the duties of librarian and has demonstrated her fitness for that increasingly important position.

High-Tension Transmission Committee

The High-Tension Transmission Committee has arranged with the Committee on Papers and Meetings to hold a special meeting of the Institute in the Auditorium of the Engineers' Building, 33 West Thirty-ninth Street, New York, on Friday, March 22, 1907, at 8 o'clock. This meeting, to be held under the auspices of the High-Tension Transmission Committee, will be devoted solely to matters relating to high-tension transmission, and the discussion will be limited to the subjects contained in the following two " Introductions to Discussion: "

1. " Feasibility of Winding Large Generators for 20,000 Volts," by B. A. Behrend, chief engineer and chief designer, Bullock Electric Manufacturing Company, Cincinnati, O.

2. " Motor-Generators versus Synchronous Converters, with Special Reference to Operation on Long-Distance Transmission Lines," by P. M. Lincoln, engineer with Westinghouse Electric and Manufacturing Company, Pittsburg, Pa.

At the request of Mr. Ralph D. Mershon, chairman of the High-Tension Transmission Committee, the Secretary urges all members of the Institute familiar with the matters referred to in these papers to assist the High-Tension Transmission Committee in its important work by contributing to the discussion, either verbally at the meeting, or, if this is not convenient, by a written contribution. If the contribution is to be a verbal one, the Secretary asks that he be notified of that fact by the contributor. If the contribution is to be a written one, it should be sent to Mr. Mershon, at his office, 60 Wall Street, New York, so that it will reach him on or before March 18, 1907.

Both these papers are printed in this issue of the PROCEEDINGS. Contributors are particularly requested to read the "Explanation" printed on the page preceding the first page of each "Introduction."

The second special meeting of the Institute under the auspices of the High-Tension Transmission Committee, will be held in Chicago in conjunction with a meeting of the Chicago Branch some time in May, 1907. The date of this meeting is not yet definitely decided. An extended notice of this meeting, including the titles of "Introductions" to be discussed, as well as the "Introductions" themselves, will be published in the March issue of the PROCEEDINGS.

The third meeting will be held at the time of the Annual Convention, at least one entire day being devoted to High-Tension Transmission matters. The titles of the "Introductions" to be discussed, as well as the "Introductions" themselves, will be published in the April issue of the PROCEEDINGS.

Institute Meetings

The following schedule has been prepared by the Committee on Papers subject to possible change due to unforeseen contingencies:

February Meeting. March 1, 1907:

Alternating-Current Electrolysis, by J. Le R. Hayden.

Electrolytic Corrosion of Iron and Steel in Concrete, by A. A. Knudson.

Some Theoretical Notes on the Reduction of Earth Currents from Electric Railway Circuits by Means of Return Feeders, by Geo. I. Rhodes.

High-Tension Transmission Committee. March 22, 1907:

Possibility of Winding Large Generators for 20,000 Volts, by B. A. Behrend.

Motor-Generators vs. Synchronous Converters, with Special Reference to Operation on Long-Distance Transmission Lines, by P. M. Lincoln.

March Meeting. March 29, 1907:

Lightning and Lightning Protection, by C. P. Steinmetz, E. E. F. Creighton, and D. B. Rushmore.

April Meeting. April 26, 1907:

Facts and Problems Relating to Electric Trunk-Line Operation, by F. J. Sprague.

May Meeting. May 24, 1907:

Some Aspects of Parallel Operation, by B. A. Behrend and A. B. Field.

Zigzag Leakage of Induction Motors, by R. E. Helmund.

Annual Convention

Papers Committee,

Rowland Telegraphic System and its Apparatus, by Frank M. Potts.

Some Power Transmission Economics, by F. G. Baum.

Notes on Transformer Testing, by H. W. Tobey.

One-phase, High-Tension Power Transmission, by E. J. Young.

Ten Years of Niagara Power, by H. B. Alverson.

Fractional Pitch Windings for Induction Motors and Alternators, by C. A. Adams.

Attitude of Technical Schools toward the Profession of Electrical Engineering, by H. H. Norris and Vladmir Karapetoff.

Engineering Specifications, by C. W. Ricker.

Vector Diagrams of One-Phase Commutating Motor, by W. I. Slichter.

Inductive Disturbances in Telephone Lines, by Louis Cohen.

And others.

High-Tension Transmission Committee,

Extra Insulation of End-Turns of Transformer Windings as a Substitute for Lightning-Arrester Choke-Coils, by S. M. Kintner.

Extra Insulation of End-Turns of Transformer Windings as a Substitute for Lightning-Arrester Choke-Coils, by Walter S. Moody.

Relative Advantages of One-Phase and Three-Phase Transformers, by H. W. Tobey.

Relative Advantages of One-Phase and Three-Phase Transformers, by John S. Peck.

Forced Oil and Forced Water Circulation for Cooling Oil-Insulated Transformers, by C. C. Chesney.

Transmission Line Towers and Economical Spans, by D. R. Scholes.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting.

Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before March 29, 1907.

5720 W. L. Macon, Philadelphia, Pa.
5721 A. R. McElhany, Mexico, Mex.
5722 G. W. Carter, Pittsfield, Mass.
5723 Carl Huper, Minneapolis, Minn.
5724 A. J. Loquin, Wilkinsburg, Pa.
5725 R. A. Morehead, Los Angeles, Cal.
5726 A. L. Pearson, W. Somerville, Mass
5727 Harry Symes, Niagara Falls, Ont.
5728 F. G. Stieler, Wilkinsburg, Pa.
5729 R. H. Sclater, Hampton, Va.
5730 H. C. Van Weelden, Brooklyn, N.Y
5731 L. O. Kuhn, New York City.
5732 P. B. Liebermann, E. Orange, N.J.
5733 C. O. Collett, Columbia, Mo.
5734 R. J. Clark, Toronto, Ont.
5735 D. R. Scholes, Chicago, Ill.
5736 B. W. Trafford, Washington, D. C.
5737 G. W. Brown, Pittsburg, Pa.
5738 W. M. Craft, New York City.
5739 J. V. B. Duer, Hempstead, L.I.
5740 D. G. Hurlbatt, Kent, England.
5741 J. B. Kittelberger, Pittsburg, Pa.
5742 Hajime Minami, Osaka, Japan.
5743 E. J. K. Mason, New York City.
5744 D. R. Pringle, Thomasville, Ga.
5745 O. C. Roff, Schenectady, N. Y.
5746 R. G. Stewart, Memphis, Tenn.
5747 A. W. Tyler, Oakfield, N. Y.
5748 F. W. Gardiner, New York City.
5749 Frank Koester, New York City.
5750 I. E. Powell, Rochester, N. Y.
5751 R. M. Phinney, Boone, Ia.
5752 E. B. Rich, Boone, Ia.
5753 H. L. Beach, Wilkinsburg, Pa.
5754 U. H. Davenport, Athens, Ga.
5755 J. W. Herman, Schenectady, N. Y.
5756 Ernst Woltman, New York City.
5757 H. S. White, Greenville, S. C.
5758 G. W. Martin, Brooklyn, N. Y.
5759 M. E. Mousselet, Wilkinsburg, Pa.
5760 C. H. Peddrick, Jr., Glens Falls.
5761 R. R. Poppleton, Portland, Ore.
5762 Wm. Aitken, Egremont, Eng.
5763 J. V. Anderson, Salt Lake City.
5764 W. J. Berry, Brooklyn, N. Y.
5765 Wm. Clayton, W. Lynn, Mass.
5766 H. N. Crandall, Baker City, Ore.
5767 A. J. Faulder, New York City.
5768 J. C. Gapen, Oak Park, Ill.
5769 A. Huntington, Sioux Falls, S. D.
5770 W. F. Hynes, E. Norwood, O.
5771 D. L. Keiser, Pittsburg, Pa.
5772 W. B. Kirkpatrick, New York City
5773 F. Longbotham, Brooklyn, N. Y.
5774 G. Mazzolani, Rome, Italy.
5775 E. D. Meyer, Chicago, Ill.
5776 F. A. Merrick, Hamilton, Ont.
5777 B. C. Nowlan, Chicago, Ill.
5778 W. McD. Nathan, Oakfield, N. Y.
5779 W. J. Poole, Glasgow, Scotland.
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Recommended for transfer by the Board of Examiners, Feb. 8, 1907. Any objection to these transfers should be filed at once with the Secretary.

ALEXANDER SUSS LANGSDORF, Professor of Electrical Engineering, Washington University, St. Louis, Mo.

LESLIE LAWRENCE PERRY, Electrical Engineer with F. S. Pearson, 25 Broad Street, New York City.

Personal

MR. WILL SPALDING has removed from Bloomington to Decatur, Ill., with the Illinois Traction System.

MR. J. EUGENE WALLACE, Engineer, of Brooklyn, N. Y., is now located at 1 Nassau Street, New York City.

MR. J. R. WHITEHEAD has left New York, and is in the office of the chief signal officer at Washington, D. C.

MR. RICHARD M. HOPKINS has changed his address from Baltimore, Md., to 520 West 175th Street, New York City.

MR. CLAXTON E. ALLEN has left Lynn, Mass., and is now with the General Electric Company, at Schenectady, N. Y.

MR. G. A. SCHNEIDER, formerly at San Francisco, Cal., has removed to Los Angeles, with the California Electric Company.

MR. J. R. BROUGHTON has been transferred from the Telluride, Colorado, office of the Telluride Power Company to Ames, Colorado.

Mr. Isaac M. Cassel has gone from Lynn, Mass., to the supply department of the General Electric Company, Schenectady, N. Y.

Mr. H. A. Dresbach, formerly electrician for B. Altman and Company, is now electrician for Van Dyck and Severn, New York City.

Mr. E. D. Bevenue-Miller, formerly with Kilburn and Company, at Calcutta, India, has removed to Cawnpore, India, as engineer for that firm.

Mr. Carl A. Schneider has gone from Montana to New Haven, Conn., where he is associated with the Consolidated Railway Company.

Mr. J. E. McGillivray has removed from the Telephone building at Walla Walla, Washington, to 125 Boren Avenue, North, Seattle, Wash.

Mr. Fletcher G. Rush has left Birmingham, Ala., and is acting as special agent for the Hartford Fire Insurance Company, at Atlanta, Ga.

Mr. C. V. Mills, formerly of Chester, Pa., is now manager and superintendent of the Lowell and Fitchburg Street Railway Company, at Ayer, Mass.

Mr. Frederick W. Hild, formerly with the General Electric Company at Chicago, Ill., has established offices at Dubuque, Iowa, as a consulting engineer.

Mr. Harold B. Vincent, formerly with the Niagara Construction Company, Ontario has removed to Buffalo, N. Y., with the Iroquois Construction Company.

Mr. Normann Malcolm has left Havana, Cuba, and is engineer with George M. Painter, contractor, 423 Chamber of Commerce Building, Chicago, Ill.

Mr. H. W. Young, formerly with the Westinghouse Electric and Manufacturing Company at Boston, Mass., has removed to the Pittsburg office of that company.

Mr. George H. Crain has left the Yonkers, N. Y., office of the Otis Elevator Company, to enter the estimating department of that company in New York City.

Mr. Paul Cheever, formerly with the Ontario Power Company, at Niagara Falls Centre, is now assistant engineer with the Telluride Power Company, at Altman, N. Y.

Mr. H. N. Latey, formerly with the Interborough Rapid Transit Company, is now senior partner, firm of Latey and Slater, engineers, at 100 Broadway, New York City.

Mr. M. F. M. Werth has removed from Baltimore to New York City, where he is engaged as superintendent of construction for the Witherbee Igniter Company.

Mr. Charles K. Stearns, mechanical and electrical engineer, has moved his office from 93 Federal street to 88 Broad street, Broad Exchange building, Boston, Mass.

Mr. Benjamin K. Hough has left New York City, and is associated with the Edison Electric Illuminating Company, at Boston, Mass., and will reside at Brookline, Mass.

Mr. Milan R. Bump, formerly with the Denver Gas and Electric Company of Denver, Colorado, is now associated with Henry L. Doherty and Company, at 60 Wall Street, New York.

Mr. Frederick H. Coble, formerly testing engineer with the Brooklyn Rapid Transit Company, has gone to Baltimore, Md., as assistant to superintendent of power, with L. B. Stillwell.

Mr. John D. Ihlder, consulting electrical engineer with the Otis Elevator Company, has changed his address from Yonkers to the offices of that company, 17 Battery Place, New York City.

Mr. Francis J. White, formerly with the Gould Storage Battery Company, is now in the electrical department of the New York Central and Hudson River Railroad Company, New York.

Mr. Norman N. Ross, formerly district engineer with the Stanley G. I. Electric Manufacturing Company, at Cincinnati, is now electrical engineer for the General Electric Company, in that city.

Mr. James S. Fitzmaurice, local honorary secretary at Sydney, New South Wales, has been appointed to the position of assistant electrical engineer in the postmaster general's department at that place.

Mr. Walter D. Steele, formerly with Westinghouse, Church, Kerr and Company, 10 Bridge street, New York, is now with the Benjamin Electric Manufacturing Company, 42 West Jackson boulevard, Chicago, Ill.

Mr. Francis J. Adams has changed his address from Westinghouse Electric and Manufacturing Company, East Pittsburg, Pa., to the Department of electrical engineering, Worcester Polytechnic Institute, Worcester, Mass.

Mr. Edward F. Schnuck has resigned his position as General Superintendent of Arbuckle Brothers in Brooklyn, N. Y., and has accepted the position of director with Jabez Burns and Sons, 542 Greenwich Street, New York City.

Mr. G. R. Radley has changed his occupation from foreman of meter and testing department of the Milwaukee Electric Railway and Light Company, to that of designing electrical engineer, with the Cutler-Hammer Company, of Milwaukee.

Mr. Henry Docker Jackson has moved his office from 4 State street, to Broad Exchange building, Boston, Mass., where he will continue his business as consulting electrical engineer with special reference to improvement in power plant economy, mill work, and power distribution for electric railways and lighting plants.

Obituary

Lewis Cammann Whitehouse, who was elected an Associate April 23, 1903, while a senior at the Stevens Institute of Technology, died recently in New York City. Mr. Whitehouse was born at New Brighton, Staten Island, June 21, 1882, and studied four years at the Staten Island Academy from which he was graduated in June 1899, and entered Stevens Institute the same year.

I see much good to come from the growth of the professional spirit in corporate management. The professional spirit is in its essence the sense of trusteeship. When the professional man takes in trust the affairs of his client, that trust becomes more binding upon him than his own personal interests. I am often amazed when I think of the vital force of this professional spirit of trusteeship. I am often astonished when I think of the great number of very commonplace men who work along year by year with sustained devotion to a true standard of professional duty. It confirms my faith in the notion that the mass of mankind like to do their duty if they can only know what it is, and that the mass of mankind desire the approbation of noble minds. It is my impression that the true professional spirit is at least as strong amongst engineers as in any other profession, and I am often tempted to think that it is stronger. Here then we see still another reason to look forward to the leadership of the engineer.—*Henry G. Prout.*

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Chicago..................1893	P. B. Woodworth.	H. R. King.	1st Tuesday after N. Y. meeting.
Cincinnati.........Dec. 17, '02	C. S. Reno.	L. Lowenberg.	
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Minnesota..........Apr. 7, '02	H. J. Gille.	Barry Dibble.	1st Friday after N. Y. meeting.
Pittsburg..........Oct. 13, '02	H. W. Fisher.	H. D. James.	2d Tuesday.
Pittsfield..........Mar. 25, '04	Gilbert Wright.	S. H. Blake.	3d Thursday.
Philadelphia.......Feb. 18, '03	W. C. L. Eglin.	H. F. Sanville.	2d Monday.
San Francisco......Dec. 23, '04	C. L. Cory.	A. H. Babcock.	
Schenectady.......Jan. 26, '03	D. B. Rushmore.	E. E F. Creighton.	2d Wednesday.
Seattle............Jan. 19, '04	C. E. Magnusson.	W. S. Wheeler.	3d Saturday.
St. Louis..........Jan. 14, '03	A. H. Timmerman.	A. S. Langsdorf.	2d Wednesday.
Toronto..........Sept. 30, '03	R. G. Black.	L. W. Pratt.	2d Friday.
Washington, D. C...Apr. 9, '03.	Edgar Russel	Philander Betts.	1st Thursday.
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Cornell University..Oct. 15, '02	E. L. Nichols.	H. H. Norris.	1st Friday after N. Y. meeting.
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Purdue University..Jan. 26, '03	C. P. Matthews.	J. W. Esterline.	Every Tuesday.
Syracuse University Feb. 24, '05	W. P. Graham	A. M. Wygant.	1st and 3d Thursdays.
Univ. of Wisconsin.Oct. 15, '02	F. M Conlee.	J. W. Shuster.	4th Thursday.
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Worcester Polytechnic Institute, Mar. 25, '04	A. P. Chapman.	A. T. Childs	
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ENGINEERS' BUILDING

DEDICATION APRIL 16 and 17, 1907

PROCEEDINGS
OF THE
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OF
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Published monthly at 33 W. 39th St., New York City, under the supervision of

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RALPH W. POPE, Editor.

Subscription. United States, Canada, Mexico and Cuba, $5 per year.
All other countries $6 per year.
Single copy 50 cents.
Subscriptions must begin with January issue.

Advertisements accepted from reputable concerns at the following net rates:

Space.	Less than half year. per issue.	Half year. per issue.	One year. per issue.
1 page	$36.00	$32.00	$30.00
½ page	22.00	18.00	16.00

Additional charges for Preferred Positions.
Professional Cards, special rate of $25 per year.

Vol. XXVI. **March, 1907.** No. 3.

The Dedication

On Tuesday, April 16, 1907, at three o'clock in the afternoon, the formal dedication exercises will begin in the Auditorium, 25 to 33 West Thirty-ninth street. The seating capacity being limited, it has been found necessary to restrict attendance by the issuing of invitations to past officers of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, and distinguished guests suggested by their representatives. In the evening of April 16 there will be a reception open to all members of the three founder societies and ladies. The entire building will be thrown open for inspection. Wednesday, April 17, will be known as Founders' Day, when brief addresses will be given by representatives of the three founder organizations, followed by the presentation of medals. This will complete the formal opening ceremonies.

The American Institute of Mining Engineers will hold its ninety-third meeting on the two days immediately following (April 18 and 19), and the American Society of Mechanical Engineers will hold its monthly meeting Thursday evening, April 18. The American Institute of Electrical Engineers will hold no professional meeting during dedication week. Three regular and one special meeting have already been held in the Auditorium, and others are to be held during the season. Those who desire to attend technical meetings will be welcome at the sessions scheduled on April 18 by the mechanical and mining engineers. Friday evening, April 19, there will be a smoker in the concert hall of Madison Square Garden, open to all members of the three founder organizations upon presentation of tickets. It is hoped that the variety of functions which are being arranged will meet the wishes of all, and that as far as possible all members within a reasonable distance of New York City will make an effort to attend.

Value of Membership

Occasionally a letter of resignation is received in which the writer states that he is so situated that he cannot attend meetings, or that he reads the Institute papers in the technical journals, the inference being that he does not get the worth of his money. Statements of this nature indicate that the writer takes such a narrow view of his profession that he loses sight of one of the most important incentives to progress. If he is so isolated, he should strive in every way to keep abreast of progress in the art. If he cannot personally meet the leaders in the electrical field, he may profit by their opinions and thoughts as recorded in the printed discussions, and these may be found in their most complete form in the monthly

PROCEEDINGS. No technical journal would undertake to print the complete discussions and papers of the Institute or any similar organization. The amount of matter continually pressing for publication in the PROCEEDINGS is so great that the question of selecting the most timely or important continually confronts the editor. The reading matter is, however, but a portion of the value of membership. Many leading engineers belong to the four national societies. They could purchase the PROCEEDINGS at a less cost than the annual dues. It is well understood that association with their fellows through the recognized organization gives them a professional standing second only to their own ability and experience. Requests are frequently received by the Secretary from city officials, capitalists, and lawyers for the names of electrical experts for certain purposes. These inquiries can only be met in a general way by furnishing a copy of the catalogue or directory of membership. It is for this reason that an electrical engineer should appreciate the importance of continuing his name on the list. It shows that he is recognized by his colleagues as being identified with the profession of electrical engineering. It is true that the larger proportion of the membership is not made up of independent electrical engineers. Many are associated with manufacturing or operating companies, but should they ever find occasion to change their positions they are likely to learn that membership in the Institute improves their standing.

Vote For or Against

THE proposed new Constitution, printed copies of which have been mailed to the membership, differs materially from the present Constitution in only three respects.

It advances the date of taking office of newly elected officers so as to enable the President to appoint his committees early enough for them properly to prepare for the ensuing season; it provides for a coördination of the work of the Branches; and it changes the method of amendment.

It is very desirable that each member should vote for or against its adoption. The present Constitution requires for the adoption of an amendment that it shall receive the affirmative vote of a majority of the members. As the membership increases it becomes more and more difficult to get an expression of opinion from over half the members. The joint ownership and occupancy of the Engineers' Building by the three founder societies, of which the INSTITUTE is one, may, because of unforeseen conditions, make it desirable again to amend the Constitution. It is therefore to be hoped that each Member and Associate will send in his vote.

A circular letter appears upon another page, which the chairman of the Committee on Local Organizations has sent to the chairmen of all Branches in which the importance of voting is clearly set forth.

Niagara Convention

AT the meeting of the Board of Directors, March 1, it was voted to hold the next convention at Niagara Falls, beginning on June 25 and continuing three or four days. This was the recommendation of the Committee on Papers after a careful consideration of various proposed locations. Four years have elapsed since a convention was held at that point, and now that suitable auditoriums are available at the hotels, it is believed that all conditions will be favorable. The remarkable scenic attractions, engineering features, and geographical situation combine to make it a most desirable place for such a gathering, and already a sufficient number of papers have been promised to make it a technical event of unusual interest. Members who wish to present papers should communicate with Chairman Stott or the Secretary as soon as possible, so that the schedule may be arranged for early publication.

Air-Cooled Transformers and Their Protection*

Transformers play a very important part in transmission systems at the present time. Two types have been used a great deal—air-cooled varnished-linen insulated, and oil-cooled oil-insulated transformers. The air-cooled transformer is cleaner to handle and repair, and there is practically no fire risk; with the oil-cooled transformer the fire risk is considerable.

The oil-cooled transformer is stronger, and will stand greater static strains; for instance, in cases of lightning, when there may be extremely high difference of potential across the coils, and discharges may occur through insulation across the coils, if the working current does not follow, the oil will fill up and reinsulate the puncture. If the working current does follow, the result will probably be a short circuit on the system, and either automatic devices or the operator will open the circuit-breakers. If the working current is not allowed to follow too long, the oil will fill up the puncture and when the transformer is thrown in again, it will not show any defect.

The air-cooled transformer will not stand up under severe static strains as well as the oil-cooled and oil-insulated transformer; for instance, if a static discharge occurs through the insulation across a coil, even though the puncture is not larger than that caused by a small sewing needle, the working current will instantly follow and start the insulation burning, which will of course disable the transformer.

There is some difference of opinion as to which is the best way to connect up the high-tension side of transformers in generating stations. One engineer prefers delta connections, and another star connections. With delta connections, if one transformer becomes disabled, a large portion of the load can be taken care of by the remaining two transformers. This can not be done where one side is connected up in star. The writer prefers the star connection on the high-tension side of transformers with the neutral or center of the star grounded. Under this condition one of the high-tension terminals of each transformer is at ground potential, and one at line potential, and use can be made of a static by-pass across each coil.

Some air-cooled transformers have six high-tension coils connected in series, wound in pancake form and placed side by side. Numbering the coil next to the line 1, and next to the center of the star 6, it has been found that test papers show severe disturbances in coils three and four while nothing has been shown in coils one or six. And again, test papers have shown severe disturbances in coils one and six while nothing has been shown in any of the other coils. Four years ago the writer examined coil 1 of a disabled transformer, and found punctures in three places in the middle layers.

In building air-cooled transformers, it seems nearly impossible to use the insulation one should, on account of sacrificing efficiency. In two years' experience with air-cooled transformers at the St. Croix Power Company's station, it was nothing unusual to see one or two transformers at the end of a 25-mile overhead line burn during a lightning storm. On account of static discharges through insulation across one or more coils, static by-passes were put across each coil, which prevented discharges through insulation across coils, although a year later discharges had taken place between the first layers of number 1 coil and the nearest low-tension coil. About that time the neutral was grounded, and since then the transformers have worked successfully for two years and without a single burn-out. It is not enough to have transformers of high efficiency; they must be able to stand up under severe static strains. If enough insulation is impracticable, then by-passes must be used.

Consider a high-tension group of

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* A paper read by John Pearson at a meeting of the Minnesota Branch, February 8, 1907.

transformers connected to a long-distance transmission line, the high-tension windings connected in star, the center of the star grounded, each transformer having six pancake coils, standing side by side, and an electric by-pass cross each coil. Consider these conditions and it is plain to see that in case of a severe static disturbance of abnormal frequency, such as is caused by lightning, that it will be easier for the transformer if the strain is divided over all the coils than if it strikes only the first coil. The brass knobs forming the by-pass have capacity to each other, and to the ground, the coils standing side by side and connected to the knobs have capacity to each other and to the ground. The high-tension coils also of course have capacity to the low-tension coils to the transformer core and frame, which should all be grounded.

By this arrangement the transformer and knobs forming the by-pass becomes to a certain extent a condenser. A condenser takes a larger current at high frequency. At low frequency the capacity of the coils and knobs is negligible; the conditions are, however, entirely different at very high frequency, where the effect of the capacity of the coils and knobs becomes noticeable. Each knob and the coil to which it is connected absorbs a charging current that is proportional to the frequency, and to the potential difference of the knobs and coils against ground. It is plain that this difference is greater when the coils are connected to the knobs than when the k o's are independent of the coils.

Experiences with Oil-insulated Transformers*

The current from the St. Croix Power Company's plant is carried underground at 25,000 volts into the heart of the business district, and is there stepped down in the St. Paul Gas Light Company's Cedar street station for use in six-phase synchronous converters and for 2200-volt alternating-current distribution. The transformers for the synchronous converters are six in number, with one spare transformer, all of 300-kw. rating, designed for 22,500 volts on the high-tension end and 78 volts supply to the converters. In addition to these there are four 200-kw. transformers with the same primary voltage but with secondaries having 25 extra taps, brought out at one terminal, with 20 volts between taps; these giving a range of voltage from 2100 to 2600 volts. These transformers are connected on the Scott system to change from three- to two-phase current, an extra primary tap being provided to give the right ratio.

All of these transformers are oil-insulated and self-cooling, they are shell-type transformers having six primary and six secondary coils. Both the primary and the secondary coils are divided into two sets of coils, four leads being brought out in each case. In the 200-kw. transformers the extra leads are dead-ended in the oil.

When the plant was started it was found that the synchronous converters would not deliver a sufficiently high voltage. The transformers at this time were connected in delta; but in order to get the necessary additional voltage the connections were changed, the connections of the primary coils being changed from series to multiple and the bank connected in star instead of delta on the primary side. By these means an increase of 15% was obtained in the secondary voltage.

With the delta connection it was not considered necessary to have any reserve transformers, since the converters could be operated on two transformers in open delta, but when the connections were changed to star, a reserve transformer became a necessity. The transformers were arranged in two banks, each feeding the converters on one side of the Edison three-wire system. In order to have the extra transformer interchangeable, it was placed between the two banks, so that the secondaries could be connected to any of the four bus-bars, fish-plates being prepared and always ready so that the damaged transformer could be cut out and the good transformer quickly substituted. On the high-tension end a pair of high-tension bus-bars were provided. One of these serving as the center of the star, has a coupling provided for connection to the spare transformer; the other is connected to the line lead of the spare transformer, and has a coupling opposite each of the active transformers, so that in the case of trouble it is only necessary to disconnect the damaged transformer and swing the line lead for that transformer over and couple to the spare bus-bar, while a similar change is made on the other bus-bar. Then the spare transformer is ready for use.

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*A paper read by F. R. Cutcheon at a meeting of the Minnesota Branch, February 8, 1907.

In regard to transformer ratios, we have had an experience that may be a warning to others in similar cases. The 200-kw. transformers, as previously stated, were built for 22,500 volts primary, and from 2100 to 2600 volts secondary. Our alternating-current distribution system does not require more than 2160 volts at any time on the station bus-bars, while the minimum voltage is 2080. This is a range of less than 5% while the direct current bus-bar voltage varies over 20%; the consequence is that in order to regulate the voltage on the direct-current system we are obliged to vary the voltage on the high-tension line at the delivery end from 20,000 volts at night to 25,000 during the peak of the load. At the latter voltage it is readily seen that the alternating-current distribution voltage could not be less than 2300 volts. This condition has only recently reached an acute phase by reason of the rapid growth of the direct-current load. It is hoped to remedy it by the use of automatic feeder regulators, which will absorb the excess voltage.

The transformers were originally intended to be placed in the main dynamo room, provided with good ventilation. Later developments, however, made this impracticable, and for lack of other space they were placed in a small closed basement. It was soon found that they could not be kept cool there except by blowing large quantities of air through the basement, and even with a 10-h.p. blower forcing the circulation the temperature rose as high as 85° or 90° cent. The makers were not willing to guarantee the transformers at this temperature and having failed in their guarantee they settled the matter by providing water-cooling coils. A well about 250 ft. deep was sunk in the station, the water from which is usually at 5° or 10° cent. and pumped about 50 gallons per minute to cool a total capacity of 2700 kw. in transformers and induction regulators. This cooling system has introduced new troubles. The first met was from atmospheric condensation on the pipes running into the oil, sometimes producing a gallon of water in a week in one transformer. The burning out of one of the 200-kw. transformers was attributed largely to this cause, hence to remedy it the pipes where exposed to air were covered with magnesia pipe covering. This has been effective.

In order to regulate the cooling of the transformers, each one was provided with a fixed thermometer and valves, and readings of the thermometers are taken during heavy load periods. In case a transformer begins to heat, it seems to exert a back pressure on the water supply which ceases entirely to flow through that coil. It is then necessary to shut off the rest of the coils, and force water through the hot coil until the coil is cooled. A system of thermostatic valves has been planned which will make this regulation automatic. The piping for the cooling coils, buried in the concrete floor, was recently discovered to be badly eaten out by electrolysis. Whether this is the work of induced alternating currents or stray direct current has not yet been determined.

During the early months of their use these transformers all leaked oil badly, the cases being in four sections, bolted and calked. As much as ten barrels of oil were used to make up the leakage during the first six months; calking or shellacing seeming to be of little use. Since the cooling coils have been put in, the leakage has been greatly reduced, though about four barrels of oil are used each year, a good share of which is lost by evaporation.

Considerable trouble was experienced from the oil soaking up through the 2200-volt leads between strands and forming a syphon. Once this action was fairly started it would remove several gallons of oil per day. To remedy this the insulation was stripped at the highest point of the leads and the strand, soldered together solidly.

When first installed, the transformers for the synchronous converters were connected up with single-conductor lead-covered cable. The induced currents in the lead were so strong as greatly to increase the heating of the cables, and where cables came in contact short circuits occurred, which vaporized large quantities of lead. Finally a large part of the lead was stripped off and the remainder insulated with wooden clamps.

Having recently installed a 1500-kw. steam-turbine alternating-current generator at the steam plant, we have endeavored to use the four 200-kw. transformers as step-up transformers, so as to operate the synchronous converters from steam power. But it has been found that the ratio of the transformers when so used is even worse than when used as step-down transformers. It is evident that in the one case voltage must be supplied to overcome the internal drop from the low-voltage end, while in the step-down transformer this extra voltage is supplied on the high-voltage end. With a regulation of 2%, this means a difference of 4% in the voltage ratio when stepping up at full load from that stepping down at full load: this effect is so marked as to make impracticable the use of the transformers in reverse.

DISCUSSION AT MINNESOTA BRANCH, FEBRUARY 8, 1907

J. C. VINCENT: If the stoppage in the flow of cooling water referred to by Mr. Cutcheon is due to the collection of air in the coils it would seem that this could be prevented by allowing the water to flow in an upward direction through the coil.

E. P. BURCH: Another method would be the connection of the water coils of the transformers in series.

J. C. VINCENT: A peculiar trouble has lately been discovered in some 550-kw. air-blast transformers. A number of fires occurred in the bases of the transformers, and these were traced to static discharges between the two piles of laminations. It was found that, probably in shipment, the laminations had got out of place, and often the two piles were nearly or quite in contact. An exploration revealed a considerable current, in some cases as much as 25 amperes flowing between the piles. This was evidently due to an induced voltage of 35 volts equivalent to one turn of the transformer. The static discharge is more difficult to account for. Sometimes the sparking would occur across a gap of $\frac{1}{16}$ inch. These troubles are being overcome by rebuilding the piles and putting in additional insulation between the laminations every half inch, then grounding each of these insulated sections to the frame of the transformer.

GEO. D. SHEPARDSON: I would suggest the possibility of the static charge, of which Mr. Vincent speaks, being due to the friction of the air blast. Another point is the desirability of grounding the section with resistance wire so that in the case of the breakdown of insulation between the sections, the local current would be limited.

A. R. FAIRCHILD: One of the transformers referred to was tested standing on the floor with no air flowing through it. The sparking was just as severe as when over the air chamber. When either pile of lamination was grounded the static sparking seemed to be increased, but when both were grounded it disappeared altogether.

J. C. VINCENT: On one transmission line, 13,000 volts, we have lost three air-blast transformers in lightning storms in the Stillwater sub-station at the end of the line, where the overhead line comes directly into the station. In another sub-station (Wildwood) about the middle of the line, the sub-station is reached through about two hundred feet of paper cable. Here we have never lost a transformer.

Chairman Spencer's Letter on Proposed Constitution

PHILADELPHIA, PA., Mar. 11, 1907.

To the Chairmen of all Branches American Institute of Electrical Engineers:

MY DEAR SIR: There will shortly be submitted to the members of the American Institute of Electrical Engineers a proposed new Constitution. The Constitution which was voted on last year failed to secure the number of affirmative votes necessary under the present Constitution for its adoption, namely, a majority of the total membership of the Institute. This was apparently due, not to any particular opposition to the proposed Constitution, as but a small percentage of negative votes was cast, but to the difficulty of getting out the large vote necessary. The Law Committee this year has prepared another revision, after carefully considering all criticisms and suggestions, and has asked the Local Organizations Committee to assist in getting out the vote so that the new revision may not be defeated simply by failure on the part of the members to express their opinions.

We feel that the proposed Constitution is favorable to the interests of the Local Organizations.

It provides for the formation of a Branch wherever there is a sufficient number of members and sufficient interest to support the work.

It does not hamper the development of any Branch by restriction as to the particular way its work should be carried on, excepting, of course, that it shall be in accordance with the aims and ideals of the Institute.

It provides that the Local Organizations Committee shall be one of the standing committees of the Institute.

It provides that the chairman of each Branch shall be a member of that committee.

It provides that the chairman of each Branch, or his alternate, shall be a delegate to the annual convention, thus providing for a body that can meet at least once a year and consider officially the interests of the Local Organizations.

Furthermore, and a matter which is of great importance, it includes an amending clause, which will permit amendments of the Constitution to be adopted in the future. It does this by providing that a proposed amendment, after being properly brought before the Board of Directors, shall be submitted by letter ballot to the entire membership, and be adopted if of sufficient general interest to bring out a vote equal to thirty per cent. of the total membership, and if three fourths of all those interested enough to vote are in favor of it.

With the largely increasing membership of the Institute we shall soon reach a point where it will be a physical impossibility to amend the present Constitution under the present amendment clauses, which require that half or more of the total membership shall vote affirmatively. This will be appreciated when it is realized that at the annual elections, even when interest has run the highest, the ballots cast for the candidates for any one office have never in total equalled a majority of the membership.

We therefore hope that you will realize the importance of getting out the vote, and will assist in arousing the interest of the members of your Branch. I would suggest that your Branch makes a direct appeal to each member, both at your first regular meeting and by circular or post card, urging him to vote on the Constitution —for it, if possible—but at any rate to cast his ballot, either for or against, so as not to let the matter go by default. Kindly urge your members to vote as soon as possible after receiving the proposed Constitution and the ballot, before the ballot has been mislaid and the matter has slipped out of mind.

With the hope that the officers of your Branch will coöperate in obtaining a decisive expression of opinion, as shown by the ballots cast for the proposed Constitution, and thanking you for such coöperation, I am,

Very truly,
PAUL SPENCER,
Chairman of Committee on Local Organizations.

Dedication Exercises

The following preliminary program has been announced in connection with the dedication of the Engineers' Building, 33 West Thirty-ninth street, New York City:

Tuesday, April 16: Formal dedication exercises in the afternoon; general reception in the evening.

Wednesday, April 17: Founders' day; addresses by representatives of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, and the American Institute of Mining Engineers, greetings from sister societies and institutions, and presentation of medals in the afternoon. The evening of this day is unassigned.

AFTER DEDICATION

Thursday, April 18: In the afternoon there will be a session of the American Institute of Mining Engineers. A paper entitled, "Mining Engineering in New York City," describing the excavation and tunnel work now being carried on by the Pennsylvania Railroad, will be presented by H. T. Hildage. In the evening there will be a session of the American Society of Mechanical Engineers, an address being delivered by Brigadier-General William Crozier, entitled, "The Ordnance Department as an Engineering Organization."

Friday, April 19: In the afternoon there will be a session of the American Institute of Mining Engineers, the details of which will be presented later. In the evening there will be a smoker for members of all the above named organizations.

Local Organizations

UNIVERSITY OF ARKANSAS

At a meeting of this Branch, held at Fayetteville, Ark., March 5, W. B. Stelzner presiding, at which were present fifteen members and thirty-five visitors, Mr. K. A. Reed was elected secretary to succeed Mr. G. C. Baker, who has quit school. Professor Schapper favored the Branch with a very interesting discussion on the "Speed of Electricity."

ARMOUR INSTITUTE

This Branch held a meeting on Jan. 25, 1907, at the Armour Institute, with a total attendance of eleven, presided over by Mr. Fred. M. Sturgess. Mr. A. L. Eustice read an original and interesting paper on the "Operation and Commercial Value of the Nernst Lamp." Several samples were shown in operation over the demonstration table.

The next meeting of this Branch. February 8, brought out a total of twenty-four. Arrangements were made for having a write-up in the *Integral*, the yearly student publication at Armour Institute. It was announced that the Institute Branch meetings would be a part of the junior and senior electrical program next term. Mr. E. E. Campbell gave a discussion on the Institute paper entitled "The Current Transformer."

At the meeting of this Branch on February 15, with a total attendance of twenty-two, Mr. E. J. Sigwalt read an original paper on "Brushes and Brush-holders." The different photographs of brush-holders were projected on the screen, and their operation explained.

BALTIMORE BRANCH

The Baltimore Branch met Feb. 8, 1907, at Johns Hopkins University, presided over by J. B. Whitehead, with an attendance of twenty-four members and nine visitors. Clayton H. Sharp read his paper " New Types of Incandescent Lamps," which was presented at the December meeting of the Institute in New York. The paper was received with much interest and appreciation, and aroused a lively discussion.

Boston Branch

At the meeting of the Boston Branch, Feb. 20, 1907, Professor H. E. Clifford presiding, there was a total attendance of sixty-nine. Mr. Farley Osgood, Associate A.I.E.E., General Manager of the New Milford Power Co., of New Milford, Conn., read a paper entitled, " Notes on Hydro-Electric Plant Organization and Operation."

[This paper will be printed in the April, 1907, Proceedings.]

Cincinnati Branch

An affiliation has been effected between the Cincinnati local branches of the American Society of Mechanical Engineers, American Society of Civil Engineers, The Engineers' Club, American Institute of Architects, and the Institute Branch. This affiliation is governed by a board of directors, consisting of two members from each of the above societies. The representatives from the electrical engineers are Messrs. Budd Frankenfield, and L. Lowenberg. At the Branch meeting February 14, L. Lowenberg presiding, with a total attendance of twenty-six, the articles of government of this association were ratified by the local section. These articles provide for the renting of suitable quarters accessible to all the members at any time during the day or evening. A library will be started by the individual societies, and all the leading technical papers and publications will be on file. A permanent secretary will be in charge of these rooms.

A paper on Wireless Telegraphy was then read by Professor Ives, the lecture being illustrated with lantern slides and complete apparatus for the sending and receiving stations. The lecture was held at the University of Cincinnati, by invitation of the faculty. After the lecture a reception, followed by refreshments, was held by the president and members of the faculty.

University of Colorado

This Branch held two meetings during February. At the first meeting papers were presented by Mr. Handley on the " Selenium Cell," and by Mr. C. E. Heaton, on " Lamp Filaments of the Latest Style." At the second meeting, Mr. Ketterman, District Manager of the Colorado Telephone Co., gave a talk on " Modern Telephone Practice." The prospects are good for increased activity in this Branch during the coming year.

Cornell University

The regular March meeting of this Branch was held in Franklin Hall on Friday, March 8. The secretary presided in the absence of the chairman. The feature of the evening was an original paper presented by Mr. J. S. Codman, rate specialist of the General Electric Co., from Boston, Mass. Mr. Codman's paper was a masterly analysis of the principles underlying equitable rates. The following synopsis which was distributed at the meeting gives an excellent idea of the scope of the paper. The attendance at the meeting was seventy. After the formal part of the exercises, an opportunity was given for the members to meet Mr. Codman, and a number took advantage of the opportunity for further discussion of the topic. The paper was fully discussed by local members, and a number of difficult points were thus explained and illustrated.

Only small part of cost of producing electricity is proportional to output of plant.

Very large proportion of fixed expenses is a peculiarity of the electrical business.

Capacity of plant determined by maximum load on plant, not by output.

Definition of load-factor.

Ideal condition, 100% load-factor.

Effect of improved load-factor on cost per kilowatt-hour.

Methods of improving load-factor.

a. Encouraging use of electricity for a variety of purposes.

b. High-efficiency lamps.

c. Scientific rates.

Rates designed to improve load-factor

a. The load-factor system.

b. The two-rate system.

Simple form of load-factor system consists of charge on maximum demand for current combined with charge on consumption.

It is a combination of the two oldest methods of charging, viz.:

a. The contract or flat-rate method.

b. The uniform-meter-rate method.

Undesirable effect of old methods.

Improvement of the uniform-meter-rate method.

Usual modifications of load-factor systems.

a. The wholesale discount.

b. The service charge or minimum bill.

c. Fixing a maximum rate per kilowatt-hour.

Wright's load-factor systems.

Reasons for fixing a maximum rate of kilowatt-hour.

a. Fixation by law.

b. Fixation by custom.

c. Fixation by theory.

d. Fixation for simplicity.

e. Fixation to satisfy public opinion.

Method of determining customers.

a. Consumption, an easy problem.

b. Maximum demand, a difficult problem.

Maximum demand.

a. Assumed equal to "connected load."

b. Estimated.

c. Measured rental of power.

d. Measured and estimated.

e. Limited.

Justifiability of load-factor system.

Misconception of the public.

Doing away with special rates.

At the preceding meeting the executive committee was increased by the addition of Mr. R. L. Stone, an undergraduate and an Associate of the Institute, who will represent the students' interests on the committee.

[Mr. Codman's paper will be published in full in the April PROCEEDINGS.]

UNIVERSITY OF ILLINOIS

Professor C. P. Matthews of the Purdue University addressed this Branch at its meeting on March 6 in the Physics Lecture Room, on the subject of "Recent Developments in Artificial Light Sources." The meeting was only fairly well attended, considering the interest that should have been developed in this subject, twenty-five members and one hundred visitors being present. Circumstances, however, prevented it from being as widely advertised as was desirable, and this undoubtedly affected the attendance.

IOWA STATE COLLEGE

A meeting of the Executive Committee was called on February 14 to discuss ways and means for the present term. The following matters were considered as desirable to present for discussion and action before the local Branch.

1. Minor changes in the Constitution of the Branch as relating to length of office, membership, and duties of officers.

2. Election of an entertainment committee.

3. Programme.

Twenty nine members of the Branch and nineteen visitors attended the meeting of February 20. Professor F. A. Fish presided. The paper of the evening was presented by Professor L. B. Spinney on the "Discussion of New Types of Incandescent Lamps." This involved the paper by Dr. Steinmetz on "Transformation of Electric Power into Light," the paper by Clayton H. Sharp on "New Types of Incandescent Lamps," and the article on the Helion Lamp published in a recent number of the *Electrical World*. The subject was ably handled by

Professor Spinney and the audience evinced keen interest during the two hours that the paper was presented and discussed. Special emphasis was laid on the excellent paper by Dr. Steinmetz as involving the theory for the production of more efficient illumination. Owing to the lateness of the hour at the conclusion of the paper, the meeting was adjourned for two weeks.

The prospects for the local Branch appear to be very promising. There are at present one Member and seven Associates on the rolls, while two other applications from this institution for enrolment as Associates have been published in the PROCEEDINGS. These in addition to one more application expected to be made soon, will, if elected, make a total of ten Associates and one Member. Only one of the above lives out of town.

MINNESOTA BRANCH

This Branch met on the evening of Jan. 11, 1907, at the office of the St. Paul Gas Light Co., Edw. P. Burch presiding. The Program Committee announced the subject for the meeting of February 8 to be "Illumination Engineering."

The chairman also announced that the annual election of officers of the Branch would occur at the next meeting.

The subject of the evening, "Transformers," was then taken up. Professor George D. Shepardson read a paper reviewing the elementary theory of the transformer, and outlining the methods by which the transformer has been adapted to various uses. F. R. Cutcheon followed with a paper entitled "Experiences with Oil-Insulated Transformers."

John Pearson next read a paper entitled, "Air-Cooled Transformers and their Protection."

[These papers and the discussion on them are printed in Section 1 of the March PROCEEDINGS.]

The annual meeting of this Branch for the election of officers for the ensuing year, was held on February 8, 1907. The election resulted as follows:

H. J. Gille, Chairman; Barry Dibble, Secretary; A. L. Abbott, C. L. Pillsbury, E. H. Scofield, Program Committee.

The following original papers were then read and discussed:

"Fundamental Principles of Illumination," H. J. Gille.

"Office Building Lighting," A. L. Abbott and J. H. Schumacher.

"Church Lighting," C. L. Pillsbury.

"Theater Lighting," Geo. Steinwedell.

UNIVERSITY OF MISSOURI

This Branch had a meeting on February 15, at Columbia, Mo., Professor H. B. Shaw presiding, with a total of twenty-three visitors and members in attendance. The subject discussed was the Institute paper "On the Substitution of the Electric Motor for the Steam Locomotive," by Lewis B. Stillwell and Henry St. Clair Putnam. The discussion was limited to the questions of reliability of service, increased capacity of line, and comparative operating expenses. The same topic is to be further considered at the next meeting.

At the meeting on March 1, with a total attendance of twenty-four, the characteristics of the series motor which specially adapt it to railway service were first considered briefly. The question of electrification of steam roads then came up for discussion. The factors affecting cost of maintenance and operation were discussed in detail. The choice of frequencies for alternating-current motors was touched on in this connection. The various advantages and disadvantages of motor-operated railway systems were set forth in the final summary.

PHILADELPHIA BRANCH

At the meeting of the Philadelphia Branch on March 11, 1907, the subject discussed was "Marine Applications of Electricity." Lieut-commander S. S. Robison presented a paper covering "United States Navy Practice in Generating Sets; Lighting; Interior Communications; and Signaling." H. M. Gleason, Assistant Naval Constructor, presented a paper covering "United States Navy Practice in Ventilation; Ammunition Handling; Turrets; Handling of Boats, etc." J. W. Kellogg of the General Electric Co., presented a paper on "Electricity in the Merchant Marine." These papers were illustrated with lantern slides.

PURDUE UNIVERSITY BRANCH

The meeting of this Branch on March 5 brought out a total attendance of one hundred and three. After the executive business was disposed of the Institute paper on "The Substitution of the Electric Motor for the Steam Locomotive," was discussed, the discussion being led by Professors C. P. Matthews, W. F. M. Goss, J. W. Esterline, and H. T. Plumb.

ST. LOUIS BRANCH

The annual meeting of this Branch was held on February 13, at the Engineers' Club, A. H. Timmerman presiding. The total attendance of members and visitors was twenty. Messrs. H. H. Humphrey, H. I. Finch, A. S. Langsdorf, J. H. Finney, and J. H. Siegfried, were elected to serve as the Executive Committee for the ensuing year. The preliminary draft of a paper dealing with the distorting effect of iron on the magnetizing current of transformers was presented by A. S. Langsdorf. The object of the investigation is to determine the relations that must hold between the amplitudes and phase positions of the fundamental and harmonics; the method of attacking the problem as explained in the preliminary draft, is partly mathematical and partly experimental. Results thus far obtained point to some very interesting and hitherto unknown relations. An interesting discussion followed, participated in by Messrs. Timmerman, Meston, Morse, and Langsdorf. The paper for the March meeting will be on "The Overload Capacity of Synchronous Motors," by Mr. Hans Weichsel.

A meeting of the Executive Committee was called for March 2, when it became known that Mr. Siegfried had in the meantime left the city. Accordingly the vacancy was filled by electing Mr. J. B. Hayes. The Executive Committee was then organized, with A. S. Langsdorf as chairman, and J. H. Finney, Secretary.

SCHENECTADY BRANCH

The March program of lectures before the Schenectady Branch has been issued. The lecture for March 4 was omitted, and an informal smoker held at Odd Fellows Hall. Messrs. C. P. Steinmetz and D. B. Rushmore spoke of the work of the Institute and of the local Branch. E. B. Raymond gave reminiscences of old times for new hearers, and Messrs. Merriam, Hill, and Thompson, contributed entertainment in a lighter vein. On Thursday, March 14, Mr. S. D. Sprong, of the New York Edison Company, lectured on the system which lights New York City. The subject for March 21 is "Arc Lighting." and will consist of an address by Richard Fleming of the General Electric Company's Lynn Works. C. W. Larson, of the Power and Mining Department, General Electric Company, will talk on Mine Locomotives and Mining on Thursday, March 28. The stereopticon will be largely used to illustrate their lectures which will increase the interest aroused by the attractiveness of the subjects and the reputation of the speakers.

SEATTLE BRANCH

The Seattle Branch held its regular monthly meeting on February 16, C. E. Magnusson presiding. Seventeen members and their friends were present. Mr. E. G. Allen gave a brief description of the Nooksach Falls Power Plant, in Whatcom Co., Washington. This water power plant is unique in being the first hydro-electric power plant located in the Washington Forest Reserve. The transmission line is forty-two miles long—the first seven miles being through very rough country in the Forest Reserve. Here the spans are sometimes five hundred feet long, where it is necessary to cross deep ravines, but the ordinary span is one hundred and forty-two feet. The wire is aluminum, of carrying capacity equal to No. 2 B. & S. gauge copper. Transmission is carried on at 22,000 volts at present, but the line is designed for 50,000 volts when necessary. The telephone line is carried on the same poles as the power line, and is seven feet below the power arm. It is of No. 10 B. & S. gauge semi-hard drawn copper and is very clear. It is transposed every tenth pole, and the power line is transposed every four miles. A discussion followed Mr. Allen's description, participated in by Messrs. W. S. Hoskins, Cyrus Whipple, C. E. Magnusson, and W. S. Wheeler.

SYRACUSE UNIVERSITY.

The Syracuse University Branch met at Smith College on February 21, with a total attendance of twenty-seven, the chairman, Dr. W. P. Graham, presiding. Professor F. E. Candler discussed " Gas Engines for Electric Generators." Mr. R. E. Bowen, '08, discussed the " Subway Construction of the Syracuse Lighting Co."

Another meeting of this Branch was held March 7, with a total attendance of sixteen. The subject discussed was the Institute paper " On the Substitution of the Electric Motor for the Steam Locomotive." The discussion was led by H. T. Brinckerhoff and H. D. Stephens. Mr. R. A. Porter, Associate Professor of Physics has been made, local secretary of this Branch.

WORCESTER POLYTECHNIC INSTITUTE

The regular meeting of the Branch was held Monday evening, March 4, 1907, in the Electrical Engineering Lecture Room, Salisbury Laboratories, with President Chapman as presiding officer. Professor Albert S. Richey, Assistant Professor of Electric Railway Engineering at Worcester Polytechnic Institute, addressed the meeting on the subject, " Electric Car Testing." The paper was the same as he presented before the New England Street Railway Club of Boston, Feb. 28, 1907, a copy of which will be published in the Street Railway Bulletin for March 1907. The first part of the paper outlines the few tests that have been made on electric cars, with special reference to the tests conducted by the W. P. I. post-graduate students on the Boston & Worcester Street Railway Company's road in the spring of 1906. The latter part of the paper describes, quite in detail, the new electric railway equipment which is being installed at the Worcester Polytechnic Institute. Total attendance at this meeting, was fifty-eight.

Minutes of Meeting of the Institute

Meeting of the American Institute of Electrical Engineers, held in the Auditorium of the Engineers' Building, 33 West Thirty-ninth street, New York, Friday, March 1, 1907. President Sheldon called the meeting to order at 8:20 o'clock.

The Secretary announced that at the meeting of the Board of Directors held during the afternoon there were 125 Associates elected as follows:

ARNOLD, LEWIS TRACY, Department Manager, Emerson Electric Mfg. Co., 2030 Washington ave.; res.; 5246 Cabanns ave., St. Louis, Mo.

BARBER, EDWIN LAMONT, Central Office Division, Bell Telephone Co.: res., 4052 West Belle Place, St. Louis, Mo.

BEARDSLEE, ROBERT WINSLOW, Engineering Department, J. G. White & Co., 43 Exchange Place, New York City.

BEEUWKES, REINIER, Assistant Engineer, N.Y. C. & H.R.R.R. Electrical Department Grand Central Station, New York City.

Benjamin, Reuben B., President, Benjamin Electric Mfg. Co.; res., 1992 Van Buren St., Chicago, Ill.

Bigler, Edward Gottlieb, Draftsman, Western Electric Co.; res., 305 Millard Ave., Chicago, Ill.

Billings, Asa White Kenney, Consulting Engineer, Empedrado 30, Havana, Cuba.

Blake, Edwin Mortimer, Professor of Mechanical Engineering, University of Arizona, Tucson, Ariz.

Borger, Henry Edwin, Electrical Engineer, Dayton Electrical Mfg. Co.; res., 670 Churchill Apartments, Dayton, O.

Bowen, Harry W., Patent Attorney, Chapin & Co., 310 Main St., Springfield, Mass.

Buck, Henry Chase, Instructor Electrical Engineering, American School of Correspondence; res., 3343 Armour Ave., Chicago, Ill.

Buckner, Ben Forsythe, Assistant Superintendent Overhead Lines, Allegheny County Light Co., res., 4619 Forbes St., Pittsburg, Pa.

Burk, Addison Brown, Jr., Assistant Construction Engineer, Electric Storage Battery Co., 1400 Association Bldg., Chicago, Ill.

Burr, Frank Daniel, Engineer on Construction, Missouri River Power Co., Canyon Ferry, Mont.

Butts, D. Jay, Engineer Salesman, Western Electric Co.; res., 235 West 128th St., New York City.

Cadby, John Nelson, Professor of Electrical Engineering, University of New Mexico, Albuquerque, N. M.

Carpenter, Leonard, Electrical Engineer, Curtis & Hine, Giddings Bldg., Colorado Springs, Colo.

Clarke, William A., Cashier, Toledo Gas Electric and Heating Co.; res., 1638 Broadway, Toledo, O.

Coe, Elmer Ransom, Assistant to Electrical Engineer, Union Switch and Signal Co., Swissvale; res., 706 Coal St., Wilkinsburg, Pa.

Coles, William Cruse, Supply Salesman, General Electric Co., Atlanta, Ga.

Craig, Frederick T., Superintendent Construction, Sultepec E. L. & P. Co., Temascaltepec, Mex.
[E. F. & part payment on dues paid.]

Creagmile, William B., Instructor in Electrical Engineering, School of Engineering, Drexel Institute, Philadelphia, Pa.
[E. F. & Dues paid.]

Crumb, William Hanford, President, W. H. Crumb & Co., 1041 First Nat. Bank Bldg., Chicago, Ill.

Cruse, George Edwin, Patent Attorney, Union Switch & Signal Co., 143 Liberty St., New York City.

Cutting, Frederick Stewart, Electrical Construction Engineer, Massie Wireless Telegraph Co., Warren, R. I.

DeForest, Cornelius W., Chief Engineer, So. Covington & Cincinnati Street Railway Co., Newport, Ky.

Dickinson, Leonard P., Assistant Professor of Electrical Engineering, Lafayette College; res., 519 High St., Easton, Pa.

d'Ornellas, Thomas Vicente, Electrical Consulting Engineer and Professor, Peruvian Government, Sta Teresa 91, Lima, Peru.

Endicott, Winthrop Tingley, Assistant on Electrolytic Investigation, Boston Elevated Railway Co., 552 Harrison Ave., Boston, Mass.

Endres, Kenneth Windram, Electrical Engineer, American Telephone & Telegraph Co., 125 Milk St., Boston, Mass.

Engel, John Gustav, Electrical Engineering Department, Twin City Rapid Transit Co., Minneapolis, Minn.

Farnell, William Clement Foster, Head Final Inspector, New York Shop Western Electric Co.; res., 118 West 49th St., New York City.

Fieux, Ernest D., Engineering and Testing Department, General Electric Co.; res., 304 Clinton St., Schenectady, N. Y.

Fournier, George Henry, Erecting Engineer, Westinghouse Electric and Mfg. Co.; res., 1433 Madison Ave., Baltimore, Md.

Garrison, Ralph Howard, Superintendent, Union Railway Supply Co., Philadelphia, Pa.; res., 59 High St., Woodbury, N. J.

Garratt, Graham Leslie, Tester, Thomson Houston General Electric Co.; res., 24 Chase St., Lynn, Mass.

Gilbert, Harold Addinsell, Draftsman, Kinsman Block System Co.; 55 Dey St., New York City.

Gordon, James Rutherford, District Manager, Westinghouse Electric and Mfg. Co., Candler Bldg., Atlanta, Ga.

Grover, William Harley, Superintendent of Fires Light and Power, Iowa State College, Ames, Ia.

Hall, Gaylord Crosette, Electrical Superintendent, Interborough Rapid Transit Co.; res., 601 W. 137th St., New York City.

Harlow, George, Designer of Transformers, British Westinghouse Electrical and Mfg. Co., Ltd., Ashwood, Timperley, Cheshire, England.

Harris, Max, General Sales Manager, Nernst Lamp Co., Pittsburg; res., 1127 Sheffield St., Allegheny, Pa.

Hart, Jack, Battery Construction, Gould Storage Battery Co., 1 W. 34th St., New York City.

Hayllar, Benjamin, Jr., Westinghouse Electric and Mfg. Co.; res., 123 West Washington Lane, Germantown, Pa.

Hewett, John Ridge, Engineer Railway Engineering Department General Electric Co.; res., 8 North Brandywine Ave., Schenectady, N. Y.

Hillman, William Bennett, Superintendant of Construction, U. S. Reclamation Service North Yakima, Wash.

Hosford, Daniel Mason, Electrical Inspector, Cleveland Inspection Bureau, 610 Park Bldg., Cleveland, O.

Hunsicker, Harry Joseph, Assistant Electrical Engineer, Hudson River Electric Power Co., 82 State St., Albany, N. Y.

Jack, Thomas Fernier, Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; res., 7519 Dickson St., Swissvale, Pa.

Jennison, Ernest Newton, Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; res., 756 Hill Ave., Wilkinsburg, Pa.

Jones, Allen Green, Insulator Specialist, General Electric Co.; res., 7 No. College St., Schenectady, N. Y.

Kemble, Parker Henry, President and General Manager, Northern Conn. Light and Power Co., Windsor Locks, Conn.

Kempton, Williard Hoyt, Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; res., 512 Rebecca Ave., Wilkinsburg, Pa.

Keyes, Corlis Gosnell, Salesman, Canadian Westinghouse Co., 99 Bay St., S. Hamilton, Ont.

Kimber, William Marmaduke Cope, Instrument Inspector, Leeds and Northrup Co., Philadelphia; res., 535 Church Lane, Germantown, Pa.

Kircher, Harry Bertram, Manager, Belleville Gas and Electric Co., Belleville, Ill.

Koenig, David, Engineer, Western Electric Co.; res., 1 Manhattan Ave., New York City.

Laciar, Bert Erwin, District Inspector, New York & New Jersey Telephone Co.; res., 9 Baldwin St., East Orange, N. J.

Lane, Harold Bouck, Testing Department, General Electric Co., Schenectady, N. Y.

Lee, Thomas Frederick, Telephone Engineer, Western Electric Co., No. Woolwich, London E., England.

Lehoczky, Paul von, Assistant Electrical Engineer, Allegheny County Light Co.; res., Southern Ave. and Simms St., Pittsburg, Pa.

LEWIS, HARRY B., Division Line Foreman, Central Union Telephone Co.; res., The Delano, Indianapolis, Ind.

LEWIS, THEODORE, Electrician and Chief Operator, F. J. G. Sub-station, Amsterdam, N. Y.

LINCOLN, JOHN CROMWELL, President, Lincoln Electric Co., 49 Wood St., Cleveland, O.

LOWNDES, ANDREW JACKSON, Engineer, Kinsman Block System Co., Wolcott, Kan.

LYON, WALDO VINTON, Assistant, Department of Electrical Engineering, Massachusetts Institute of Technology, Boston, Mass.

MACDOWELL, ANDREW SEMPLE, District Engineer, Westinghouse Electric and Mfg. Co., University Bldg., Syracuse, N. Y.

MAHOOD, DAVID M., Chief Sub-inspector Equipment Department New York Navy Yard; res., 344 6th Ave., Brooklyn, N. Y.

MAIBAUM, JEROME, Designer, New York Edison Co.; res., 169 E. 80th St., New York City.

MARTIN, JAMES FRANK, Foreman in Testing Laboratory, Allegheny County Light Co.; res., 311 Lehigh Ave., Pittsburg, Pa.

MCDERMOTT, FRANKLIN PIERCE, JR., Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; res., 920 Ross Ave., Wilkinsburg, Pa.

MCQUISTON, JACKSON CLERDENON, Manager, Westinghouse Electric and Mfg. Co.; res., 10 Mifflin Ave., Edgewood, Park, Pa.

MEES, CURTIS ADOLPH, Charge of Design, Southern Power Co., Charlotte, N. C.

MILES, FREDERICK, Superintendent of Power, New Milford Power Co., Gaylordsville, Conn.

MILLER, ANDREW OTTERSON, Correspondent, Westinghouse Electric and Mfg. Co., 11 Pine St., New York City.

MOORE, WILLIAM J., Electrician, Price Elec. & Cons. Co., Newcastle, Pa.

MORSE, ARTHUR CURTIS, Technical Salesman, Western Electric Co., 463 West St., New York City; res., 104 Summit Ave., Summit, N. J.

MORSE, ERNEST CADWELL, Sales Engineer, Westinghouse Electric and Mfg. Co., Boston; res., 11 Dix St., Worcester, Mass.

MURPHY, PATRICK JOSEPH, Electrical Engineer, Ford, Bacon and Davis, 24 Broad St., New York City.

MUSSER, MARC JAMES, Engineering Department, North Shore Electric Co., Evanston, Ill.

MYERS, ERAL COLMAN, Haenig Electric Co., Springfield, Ill.

NICKELS, CHARLES BURTON, Assistant to General Manager, Toledo Gas, Electric and Heating Co.; res., 529 Acklin Ave., Toledo, O.

OESTERREICHER, SANDOR IGNATI, Electrical Draftsman, New York Edison Co., New York City; res., 342 High St., Newark, N. J.

PEAKER, WILLIAM JAMES, Draftsman, Lake Superior Power Co., Saulte Ste Marie, Ont.

POLLARD, NELSON LEVI, Electrical Engineer, Ford, Bacon and Davis, 2100 1st Ave., Birmingham, Ala.

POTTS, ALFRED GILBERT, Engineer, Union Railway Supply Co., 1633 Real Estate Trust Bldg.; res., 1627 N. 32d St., Philadelphia, Pa.

RALSTON, ALBERT LENNERT, Electrical Engineer, Westinghouse Electric and Mfg. Co.,, Pittsburg; res., 1000 South Ave., Wilkinsburg, Pa.

READ, WALTER VAN HOUTEN, Transmission Inspector, Central District and Printing Co. Telegraph, Pittsburg, Pa.

REID, WALTER DAVID, Telephone Engineer, American Telephone and Telegraph Co., 125 Milk St., res., 41 Pinckney St., Boston, Mass.

Riley, Champlain Lord, Consulting Engineer, Clark and MacMullen, 20 Broad St., New York City; res., 7 Myrtle Ave., Plainfield, N. J.

Riley, 2d, Lewis Adams, Operating Department, J. G. White & Co., 43 Exchange Pl.; res., 114 W. 80th St., New York City.

Robinson, Paul, Division Superintendent, California Gas and Electric Corporation; res., 2520 Hillegas Ave., Berkeley, Cal.

Rodman, Walter Sheldon, Instructor in Physics and Electrical Engineering Rhode Island College, Kingston, R. I.

Rossman, Frank Fox, Salesman, Westinghouse Electric and Mfg. Co., 600 Bank of Commerce, St. Louis, Mo.

Sanderson, Clarence Herbert, Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

Shuff, Frank K., Chief Engineer, Iowa State College, Ames, Iowa.

Schumacher, John Henry, Assistant Superintendent of Construction, W. I. Gray & Co.; res., 2716 University Ave., S. E., Minneapolis, Minn.

Shute, Henry Damon, Assistant to Vice-president, Westinghouse Electric and Mfg. Co.; res., 424 Emerson St., Pittsburg, Pa.

Schwecke, Henry C., Electrical Engineer. General Electric Co.; res., 277 Glenwood Blvd., Schenectady, N. Y.

Selden, George Kearsley, Construction Engineer, Chesapeake & Potomac Telephone Co., 722 12th St., N. W., Washington, D. C.

Skehan, Eugene Augustine, Engineer New York Edison Co., New York City; res., 913 St. Johns Pl., Brooklyn, N. Y.

Smith, Seth Barton, District Manager, Canadian Westinghouse Co., Ltd., Vancouver, B. C.

Stanley, Howard Arthur, Outside Construction Foreman, Stanley G. I. Electric Mfg. Co., Pittsfield, Mass.

Summerhill, Ernest John, Supervising Engineer, British Westinghouse Electric and Mfg. Co., Ltd., Collingwood Buildings, Newcastle on Tyne, England.

Tatem, Clifford Ross, Technical Salesman, Allis-Chalmers Co.; res., 40 Gibbs St., Rochester, N. Y.

Taylor, Henry William, Designing Engineer, British Thomson Houston Co.; res., 37 Temple St., Rugby, Eng.

Thomas, Royal David, Oakmont, Pa.

Thomson, Robert Richardson, Agent, General Electric Co., 1003 Majestic Bldg., Detroit, Mich.

Thomson, William Hargadine, Jr., Assistant to General Manager, St. Paul Gas Light Co., St. Paul, Minn.

Todd, William Newman, Assistant Electrical Engineer, Portland Co., 39 Cumberland Ave., Portland, Me.

Tonkin, Juan, Contracting Engineer, J. G. White & Co., 43 Exchange Pl.; res., 420 W. 121st St., New York City.

Tower, Charles Homer, Instructor. Cornell University; res., 103 Quarry St., Ithaca, N. Y.

Trawick, Samuel Wilkins, Agent, Railway Department, General Electric Co., 44 Broad St.; res., 562 W. 148th St., New York City.

Tripp, Charles A., Partner, McMeans and Tripp, 607 State Life Bldg., Indianapolis, Ind.

Troy, Daniel W., Electrical Expert, Stewart & Stewart, 60 Wall St.; res., 111 W. 104th St., New York City.

Van Staagen, Harry H., Salesman, Westinghouse Electric and Mfg. Co., 705 Land Title Bldg., Philadelphia, Pa.

Visscher, Oswald William, Engineering Salesman, Western Electric Co., 11th and York Sts., Philadelphia, Pa.

Wagner, Jean Robert, Foreman Meter Department, New York Edison Co.; res., 238 E. 124th St., New York City.

WATERS, HENRY LANGWORTHY, Assistant Electrical Engineer, Central District and Printing Telegraph Co., Pittsburg, Pa.

WELSH, JAMES WINFIELD, Assistant Electrician Pittsburg Railways Co., res., 120 Oakview Ave., Edgewood Park, Pa.

WESTBROOK, FRANCIS ABEKEN, Electrician, Engineering Department New York and New Jersey Telephone Co.; res., 37 Strong Pl., Brooklyn, N. Y.

WILDER, GEORGE WALKER, Telephone Engineer, 1761 Monadnock Bldg.; res., 5848 Prairie Ave., Chicago, Ill.

WILLIAMS, LOUIS, Superintendent, United Towns Electrical Co., Ltd., Carbonear, Newfoundland.

WILLIAMS, PAUL FRANCIS, Assistant General Inspector, Chicago Edison and Commonwealth Electric Co., 139 Adams St., Chicago, Ill.

McCARTHY, DANIEL JOSEPH, Union Switch and Signal Co., Swissvale; res., 608 Lamar St., Wilkinsburg, Pa. Total, 125.

The Secretary further announced that the following Associates were transferred to the grade of Member:

L. S. RANDOLPH, Consulting Engineer, Blacksburg, Va.

ALBERT CAVALLO JEWETT, Electrical Adviser to Government Kashmir (India) Baniar, Jhelum Valley Road, Kashmir, India.

WILLIAM CORBIT SPRUANCE, JR., Consulting Engineer, Equitable Bldg., Wilmington, Del.

HARRY ELLSWORTH CLIFFORD, Professor of Theoretical Electricity, Massachusetts Institute of Technology, Boston, Mass.

EDGAR DAVIS EDMONSTON, Chief Engineer American Construction Co., New Orleans, La.

GEORGE ROY WOOD, Consulting Electrical Engineer, 1021-1023 Fulton Bldg., Pittsburg, Pa.

LEE DE FOREST, Wiress Telegraph Development, 315 West 97th St., New York City.

WILLIAM C. L. EGLIN, Electrical Engineer, Philadelphia Electric Co., 10th and Sansom Sts., Philadelphia, Pa.

PETER COOPER HEWITT, Scientist, 11 Lexington Ave., New York City.

The Secretary aunounced further that upon the recommendation of the Committee on Papers and Meetings the Board of Directors had decided to hold the Annual Convention at Niagara Falls, New York, beginning Tuesday, June 25, 1907.

The following papers were then presented:

1. Alternating-Current Electrolysis, by J. Le R. Hayden.

2. Electrolytic Corrosion of Iron and Steel in Concrete, by A. A. Knudson.

3. Some Theoretical Notes on the Reduction of Earth Currents from Electric Railway Circuits by Means of Return Feeders, by Geo. I. Rhodes.

The following members took part in the discussion: Messrs. Stillwell, Waterman, Winsor, Corning, Kintner, Townley, Sever, Ganz, and Steinmetz.

Increase of Membership.

In response to the appeal of the Committee on Increase of Membership, asking members to suggest persons who would be likely to be interested in the work of the Institute, from 900 to 1000 names have been received. Among these are many names of persons holding positions of responsibility; persons who would make notable additions to our roll. The interest in the work of the Institute that has been manifested by many members who have taken the trouble to send in several names on the reply postals sent out by the Committee, is very satisfactory. The interesting of these non-members in the organization cannot fail to be of great benefit both to themselves and to the Institute. The Committee requests that any postals still in the hands of members be returned as promptly as possible.

Institute Meetings

The following schedule has been prepared by the Committee on Papers, subject to possible change due to unforeseen contingencies:

April Meeting, April 26, 1907:

"Light from Gaseous Conductors within Glass Tubes—The Moore Light," by D. McFarlan Moore.

May Meeting, May 24, 1907:

"Facts and Problems Relating to Electric Trunk-Line Operation," by F. J. Sprague.

A special meeting of the Institute under the auspices of the High-Tension Transmission Committee will be held in Chicago, in conjunction with the Chicago Branch, on May 24, 1907. A detailed notice of this meeting will appear in the April PROCEEDINGS.

Annual Convention, Niagara Falls, N. Y.

JUNE 25–28, 1907

Papers Committee:

"Rowland Telegraphic System and its Apparatus," by Frank M. Potts.

"Some Power Transmission Economics," by F. G. Baum.

"Notes on Transformer Testing," by H. W. Tobey.

"Single-phase, High-Tension Power Transmission," by E. J. Young.

"Ten Years of Niagara Power," by H. B. Alverson.

"Fractional Pitch Windings for Induction Motors and Alternators," by C. A. Adams.

"Attitude of Technical Schools toward the Profession of Electrical Engineering," by H. H. Norris and Valdemir Karapetoff.

"Signal Engineering," by L. F. Howard.

Topical Discussions:

1. "Single-Phase versus Multiphase Generators for Alternating-Current Roads."
2. "Standardizing the Frequency for Alternating-Current Roads."

By A. H. Armstrong, railway engineering department, General Electric Company, Schenectady, N Y.; and N. W. Storer, railway engineering department, Westinghouse Electric & Manufacturing Company, Pittsburg.

"Engineering Specifications," by C. W. Ricker.

"Vector Diagrams of Single-Phase Commutating Motor," by W. I. Slichter.

"Inductive Disturbances in Telephone Lines," by Louis Cohen.

And others.

High-Tension Transmission Committee.

By special arrangement with the chairman of the High-Tension Transmission Committee, one entire day of the annual convention will be devoted solely to matters relating to high-tension transmission. The following "Introductions" will be presented:

Extra Insulation of End-Turns of Transformer Windings as a Substitute for Lightning-Arrester Choke-Coils, by S. M. Kintner.

Extra Insulation of End-Turns of Transformer Windings as a Substitute for Lightning-Arrester Choke-Coils, by Walter S. Moody.

Relative Advantages of Single-Phase and Three-Phase Transformers, by H. W. Tobey.

Relative Advantages of Single-Phase and Three-Phase Transformers, by John S. Peck.

Forced Oil and Forced Water Circulation for Cooling Oil-Insulated Transformers, by C. C. Chesney.

Transmission Line Towers and Economical Spans, by D. R. Scholes.

High Tension Transmission Committee

The High-Tension Transmission Committee arranged with the Committee on Papers and Meetings to hold a special meeting of the Institute in the Auditorium of the Engineers' Building, 33 West Thirty-ninth Street, New York, on Friday, March 22, 1907, at 8 o'clock. This meeting was held under the auspices of the High-Tension Transmission Committee, and devoted solely to matters relating to high-tension transmission. The discussion was limited to the subjects contained in the following two "Introductions to Discussion:"

1. "Feasibility of Winding Large Generators for 20,000 Volts," by B. A. Behrend, chief engineer and chief designer, Bullock Electric Manufacturing Company, Cincinnati, O.

2. "Motor-Generators versus Synchronous Converters, with Special Reference to Operation on Long-Distance Transmission Lines," by P. M. Lincoln, engineer with Westinghouse Electric and Manufacturing Company, Pittsburg, Pa.

At the request of Mr. Ralph D. Mershon, chairman of the High-Tension Transmission Committee, the Secretary urges all members of the Institute familiar with high-tension transmission matters to assist the High-Tension Transmission Committee in its important work by contributing to the discussions on the various "Introductions" to be printed in the April and May issues of the PROCEEDINGS. If the contribution is to be a written one, it should be sent to Mr. Mershon, at his office, 60 Wall Street, New York. Contributors are particularly requested to read the "Explanation" to be printed on the page preceding the first page of each "Introduction."

A. S. M. E. Transactions

The council of the American Society of Mechanical Engineers has granted to the members of the American Institute of Mining Engineers and the American Institute of Electrical Engineers the privilege of purchasing its publications at the rates allowed to its own members. A reciprocal arrangement has been made by the Board of Directors on behalf of the Institute.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting.

Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before April 26, 1907.

5853 W. L. DeBaupre, S. Bethlehem, Pa.
5854 C. Holden, Winnipeg, Can.
5855 H. H. Boyd, Winnipeg, Can.
5856 J. F. Boyley, Loughboro, Eng.
5857 M. Ferry, San Francisco, Cal.
5858 J. S. Kerins, New York City.
5859 C. G. Stoll, Chicago, Ill.
5860 C. J. G. Bergendall, Reading, Pa.
5861 M. O. Bolser, Ames, Iowa.
5862 P. R. Farrow, Kakabekaa Falls.
5863 W. J. Hill, Jr., New York City.
5864 P. D. Honeyman, New York City.
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Total, 156.

Applications for Transfer.

Recommended for transfer by the Board of Examiners, March 15 and 22, 1907. Any objection to these transfers should be filed at once with the Secretary.

C. WELLINGTON KOINER, Electrical Engineer, 420 Olive Street, St. Louis, Mo.

C. E. MAGNUSSON, Associate Professor Electrical Engineering, University of Washington, Seattle, Wash.

L. H. THULLEN, Electrical Engineer, Union Switch and Signal Co., Pittsburg, Pa.

ROBERT FRANCIS HAYWARD, General Manager Mexican Light & Power Co., Ltd., Mexico, D. F.

PETER JUNKERSFELD, Electrical Engineer, Chicago Edison Co., Chicago, Ill.

ALBERT B. HERRICK, Consulting Electrical Engineer, Ridgewood, N. J.

Friendly Finance

A check for $50,000, the largest amount ever negotiated through the Institute's treasury, was handed to Chairman T. Commerford Martin on March 21, and represented the contribution of the Westinghouse companies to the building funds of the three founder societies. It was delivered to Chief Clerk Macnabb on March 25 and deposited the same day in the Fifth Avenue branch of the Farmers' Loan and Trust Company. Two checks each representing one third of the amount were sent to Treasurer Hamilton to be signed, and on March 26 were delivered to the American Society of Mechanical Engineers and the American Institute of Mining Engineers. Mr. Martin has been a most enthusiastic advocate of the belief that the large manufacturing companies owe much of their success to the work of the national engineering organizations. The phenomenal growth of the Land Building and Endowment Fund proves that his faith and work make a winning combination.

Personal.

MR. R. CROWELL has removed from Sutter Creek, to Electra, Cal.

MR. GEORGE M. MAYER, mechanical and electrical engineer, has removed from Chicago, to Elkhart, Ind.

MR. E. L. FARRAR is now in the induction motor department of the General Electric Company, at Schenectady, N. Y.

MR. T. C. JAMES has left Buffalo, N. Y., and is associated with the Allis-Chalmers-Bullock Company, at Montreal.

MR. BENJAMIN MAGNUS, metallurgical engineer, has removed from Martinez, Cal., to 19 West 94th street, New York City.

MR. J. S. VIEHE is now associated with the Federal Construction Company Rockingham, N. C., as electrical engineer.

MR. HAROLD B. ATKINS, formerly of Roselle, N. J., is with Dodge and Day, engineers, Drexel Building, Philadelphia, Pa.

MR. DAVID F. HUDDLE, JR., is now in the switchboard department of the General Electric Company, at Schenectady, N. Y.

MR. A. J. J. PFEIFFER has been made general manager and chief engineer of the Calcutta Tramways Company, Calcutta, India.

MR. W. GODFREY T. R. POPE, formerly of London, Eng., is now with La Union Telephonica, 1193 Rivadavia, Buenos Ayres, A. R.

MR. F. S. DENNEEN, formerly assistant manager of the Ohio Brass Company, is now commercial engineer for the same company.

Mr. E. G. Elliott has left Perth Amboy, N. J., and is associated with the Selby Smelting and Lead Company, South San Francisco, Cal.

Mr. William J. Smith, formerly with Robbins and Myers, is now manager of the Wallace-Smith Company, 19 Murray street, New York City.

Mr. H. S. Williston, formerly of New York City, is now with the Massachusetts Electric and Manufacturing Co., of West Lynn, Mass.

Mr. E. W. Ackland has left Noyes Bros., Dunedin, N. Z., and is with the National Electrical and Engineering Company of Dunedin, N. Z.

Mr. Charles W. Hogan, formerly with the American Electric Lamp Company, is with the Novelty Incandescent Lamp Company, Emporium, Pa.

Mr. Martin O. Southworth has left Indianapolis, to become engineer of electrical department with Fairbanks, Morse and Company, of Chicago, Ill.

Mr. Joseph B. Baker, formerly with the General Electric Company at Schenectady, is now technical editor, fuel investigations, at Washington, D. C.

Mr. Henry L. Fridenberg, formerly of Tonopah, Nev., is now with the Nevada Smelting and Mines Corporation at 25 Broad street, New York City.

Mr. Wm. G. Davis, formerly of Washington, D. C., is now with the Westinghouse Machine Company, No. 10 Bridge street, as storage battery sales engineer.

Mr. A. E. Wood, formerly with the Stanley G. I. Electric Manufacturing Company of Pittsfield, Mass., is now with the Trumbull Electric Manufacturing Company, at Plainville, Conn.

Mr. W. C. Forsythe has changed his address from Tallahassee, Fla., to Mobile, Ala., where he is associated with the Mobile Electrical Supply Company.

Mr. A. W. K. Peirce, formerly electrical engineer, Consolidated Gold Fields of South Africa, is now with the Victoria Falls Power Company, London, Eng.

Mr. W. A. Duff has removed from the Montreal office of the Canada Westinghouse Company, Ltd., to the same Company's address at Winnipeg, Manitoba.

Mr. Lawrence W. Cady has removed from Cambridge, Mass., and is now chief engineer of the W. J. Barr Electric and Manufacturing Company, of Cleveland, O.

Mr. William W. S. Butler is at present general manager and engineer for the Newport News and Old Point Railway and Electric Company, Hampton, Va.

Mr. Harry L. St. George has changed his address from Fidelity Building, Buffalo, N. Y., to 60 Wall street, New York City, with Ralph D. Mershon.

Mr. J. I. Matthias, formerly with the Philadelphia Electric Company, is now associated with the Licking Light and Power Company at Newark, O., as manager.

Mr. Henry John Golding, electrical engineer, formerly with the Western Electric Company of Chicago, is now with Elliott Bros., Lewisham, London, S. E., Eng.

Mr. Walter B. Gump has left the Cleveland Construction Company, and is now located at 2510 Juliet Ave., Los Angeles, Cal., as electrical and mechanical engineer.

MR. F. G. **PROUTT** has removed from Memphis, Tenn., and is now general manager of the Jackson Electric Railway Light and Power Company, at Jackson, Miss.

MR. J.G. **BLAINE REPLOGLE**, formerly with Jos. Saltzman Company, of Chicago, is now assistant electrical inspector for the Western Electric Company, of Chicago.

MR. W. H. **ACKER** has changed his address from the Westinghouse Electric and Manufacturing Company, to the West Penn Railways Company, Connellsville, Pa.

MR. S. **EDGAR WHITAKER**, formerly of Portland, Me., has been appointed office manager of the American Society of Mechanical Engineers, 29 West 39th street, New York City.

MR. **CLARENCE** H. **ELLIS**, formerly with the Georgia Florida Mill Company, at Alton, Fla., has accepted the position of superintendent of the city electric light plant at Tallahassee, Fla.

MR. **THOMAS** L. **MORRILL**, formerly with the Mexican Light and Power Company, at El Oro, Mex., is electrical engineer for the Compana de Potencia Electrica de Colima, Colima, Mex.

MR. G. S. **MALTHA** has left the Westinghouse Electric and Manufacturing Company of Pittsburg, to accept a position as electrical engineer with the Western Electric Company at Chicago.

MR. **EARL** D. **SILVER** has left the position of chief engineer of the State Prison at Michigan City, Indiana, and is now electrical engineer with the Western Electric Company, Hawthorne, Ill.

MR. **LOUIS** C. F. **NAUTRE**, formerly with the Empire State Power Company, of Amsterdam, N. Y., is now engaged as test expert with Morton Havens, Jr., constructing engineer, 79 Chapel street, Albany, N. Y.

MR. O. I. **EBERHART** has resigned his position with the Crocker-Wheeler Company at Ampere, N. J., and is now in the sales department of the Westinghouse Electric and Manufacturing Company, Philadelphia office.

MR. **FRANK GAIENNIE**, JR., has left his position as superintendent of switchboards with the Kinloch Telephone Co., of St. Louis, Mo., his present address being, electrical engineer, Apartado 154, Oaxaca, Mexico.

MR. **JAMES** F. **MEISTER**, formerly with the Westinghouse Electric and Manufacturing Co., at East Pittsburg, Pa., has accepted a position with the Stone and Webster Corporation, 84 State street, Boston, Mass.

MR. J. **WALTER GILLETTE** has resigned from his position as engineer with the National Battery Company of Buffalo, N. Y., to assume the management of the Fort Smith Light and Traction Company, Fort Smith, Ark.

MR. **CALVIN** W. **RICE**, recently consulting engineer with the General Electric Company, 44 Broad street, has been appointed secretary of the American Society of Mechanical Engineers, 29 West 39th Street, New York City.

MR. **SYDNEY** W. **BROWN**, formerly with the British Columbia Railway Company of Vancouver, has taken the position of construction engineer with the Canadian Westinghouse Company, Sovereign Bank Building, Montreal.

MR. **SANFORD DAVIS** has changed his address from the Canada General Electric Company, 148 Notre Dame East, Winnipeg, to the Canadian General Electric Company, engineering department, 14 King street, East, Toronto.

MR. E. C. CREAGH has left his position of assistant engineer for Noyes Bros., Dunedin, N. Z., to go to the transformer department of the British Westinghouse Electric and Manufacturing Company, Trafford Park, Manchester, Eng.

MR. CLARENCE E. DELAFIELD has resigned his position with the Wagner Electric and Manufacturing Company, as St. Louis district manager, and is now connected with the Ohio Brass Company, at Mansfield, O., as manager of the high tension division.

MR. WALTER G. CLARK, Vice-president of the Kilbourne and Clark Company, at Seattle, Wash., has changed his address to 135 Broadway, New York City, being president respectively of the Parker Clark Electric Company, the Clark Electric and Manufacturing Company, and the Clark and Cowles Valve Company.

MR. JOSE DE STA CECILIA has resigned his position with Messrs. Trajano de Medeiros and Company, and has accepted the situation of chief electrical engineer for the municipality of Bello Horizonte, capital of the State of Minas, Brazil, in charge of the hydro-electric plant for lighting, power and tramways. He will also supervise the construction of the new plant, 3200 h.p. capacity, 45 kilometre, 40,000 volts transmission line.

MR. M. J. WIGHTMAN, Member A.I.E.E., has filed with the city clerk of Seattle, Wash., his acceptance of the recently granted Fourth Avenue S. *et al* franchise. This franchise requires the grantees, their successors and assigns, to construct an interurban line between Seattle and Tacoma, and have the same in operation prior to July, 1909. This line will be about 30 miles in length, and will be several miles shorter than the Seattle and Tacoma Interurban line now in operation.

Obituary

JAMES BLAKE CAHOON, former president of the National Electric Light Association, died at his home in New Rochelle, N. Y., February 17, 1907. Mr. Cahoon was born at Lyndon, Vt., December 22, 1856, and graduated from the United States Naval Academy in 1879, subsequently taking a post-graduate course in electricity and chemistry at the Torpedo School. In 1889 he was appointed manager of the expert department of the Thomson-Houston Electric Company at Lynn, Mass. In 1895 he became general manager of the Elmira Municipal Improvement Company operating the electric railway gas and water plants of the city. During the war with Spain he served as a volunteer, and was given honorable mention for excellent service. Mr. Cahoon was elected an Associate June 17, 1890, and transferred to the grade of Member May 19, 1891. He was appointed a member of the Board of Examiners by President Duncan in 1895, and served three years. At the time of his death he was vice-president of the Eldenbel Construction Company at 42 Broadway.

FRANK L. FREEMAN, patent attorney, died in Washington, D. C., Tuesday, March 5, 1907. He was a native of Massachusetts, having been born in Marlborough April 25, 1847. He was for three years principal examiner in charge of the class of electricity in the United States Patent Office, resigning in 1883 to practice patent law. He was one of the government commissioners to the Paris Electrical Exposition in 1881, and served on one of the juries. He was a member of the Institution of Electrical Engineers of Great Britain. Dr. Freeman was frequently called upon to testify as an electrical expert in the courts. He was elected an Associate May 7, 1889, and transferred to the grade of Member September 3, 1889.

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BRANCHES.			
Atlanta............Jan. 19, '04	A. M. Schoen.	W. R. Collier.	
Baltimore.........Dec. 16, '04	J. B. Whitehead.	C. G. Edwards.	2d Friday.
Boston............Feb. 13, '03	H. E. Clifford.	C. H. Porter.	3d Wednesday
Chicago..................1893	P. B. Woodworth.	H. R. King.	1st Tuesday after N. Y. meeting.
Cincinnati.........Dec. 17, '02	C. S. Reno.	L. Lowenberg.	
Columbus.........Dec. 20, '03	F. W. C. Bailey.	H. L. Cook.	1st Monday.
Minnesota..........Apr. 7, '02	H. J. Gille.	Barry Dibble.	1st Friday after N. Y. meeting.
Pittsburg..........Oct. 13, '02	H. W. Fisher.	H. D. James.	2d Tuesday.
Pittsfield..........Mar. 25, '04	Gilbert Wright.	S. H. Blake.	3d Thursday.
Philadelphia.......Feb. 18, '03	W. C. L. Eglin.	H. F. Sanville.	2d Monday.
San Francisco......Dec. 23, '04	C. L. Cory.	A. H. Babcock.	
Schenectady.......Jan. 26, '03	D. B. Rushmore.	E. E F. Creighton.	2d Wednesday.
Seattle............Jan. 19, '04	C. E. Magnusson.	W. S. Wheeler.	3d Saturday.
St. Louis..........Jan. 14, '03	A. S. Langsdorf.	J. H. Finney.	2d Wednesday.
Toronto..........Sept. 30, '03	R. G. Black.	L. W. Pratt.	2d Friday.
Washington, D. C...Apr. 9, '03.	Edgar Russel	Philander Betts.	1st Thursday.
UNIVERSITY BRANCHES.			
Cornell University..Oct. 15, '02	E. L. Nichols.	H. H. Norris.	1st Friday after N. Y. meeting.
Iowa State College..Apr. 15, '03	F. A. Fish.	Adolph Shane.	1st Wednesday.
Lehigh University..Oct. 15, '02	A. W. Lawson.	M. T. Saldana.	3d Thursday
Purdue University..Jan. 26, '03	C. P. Matthews.	J. W. Esterline.	Every Tuesday.
Syracuse University Feb. 24, '05	W. P. Graham	R. A. Porter.	1st and 3d Thursdays.
Univ. of Wisconsin.Oct. 15, '02	F. M Conlee.	J. W. Shuster.	4th Thursday.
Univ. of Illinois....Nov. 25, '02	Morgan Brooks.	M. K. Akers.	1st Wednesday
Worcester Polytechnic Institute, Mar. 25, '04	A. P. Chapman.	A T. Childs	
STUDENT MEETINGS.			
Armour Institute...Feb 26, '04	C. E. Freeman	C. E. Freeman	3d Monday
Ohio State Univ....Dec 20, '02	H. C. Bartholomew	F. E. Beutler	Every Tuesday evening
Penn. State College.Dec 20, '02	C. L. Christman	H. L. Frederick	Every Wednesday
Univ. of Arkansas..Mar 25, '04	W. B. Stelzner.	K. A. Reed.	1st & 3d Tuesdays
Univ. of Colorado..Dec 16, '04	J. N. Kellogg.	A. C. Streamer.	1st and 3d Wednesdays
Univ. of Michigan..Mar 25, '04	Kenneth Barry	C. J. Whipple.	1st and 3d Wednesdays
Univ. of Missouri...Jan 10, '03	H. B. Shaw	H. D. Carpenter.	1st and 3d Fridays
Washington Univ...Feb 26, '04	A. S. Langsdorf	W. E. Bryan.	1st Wednesday

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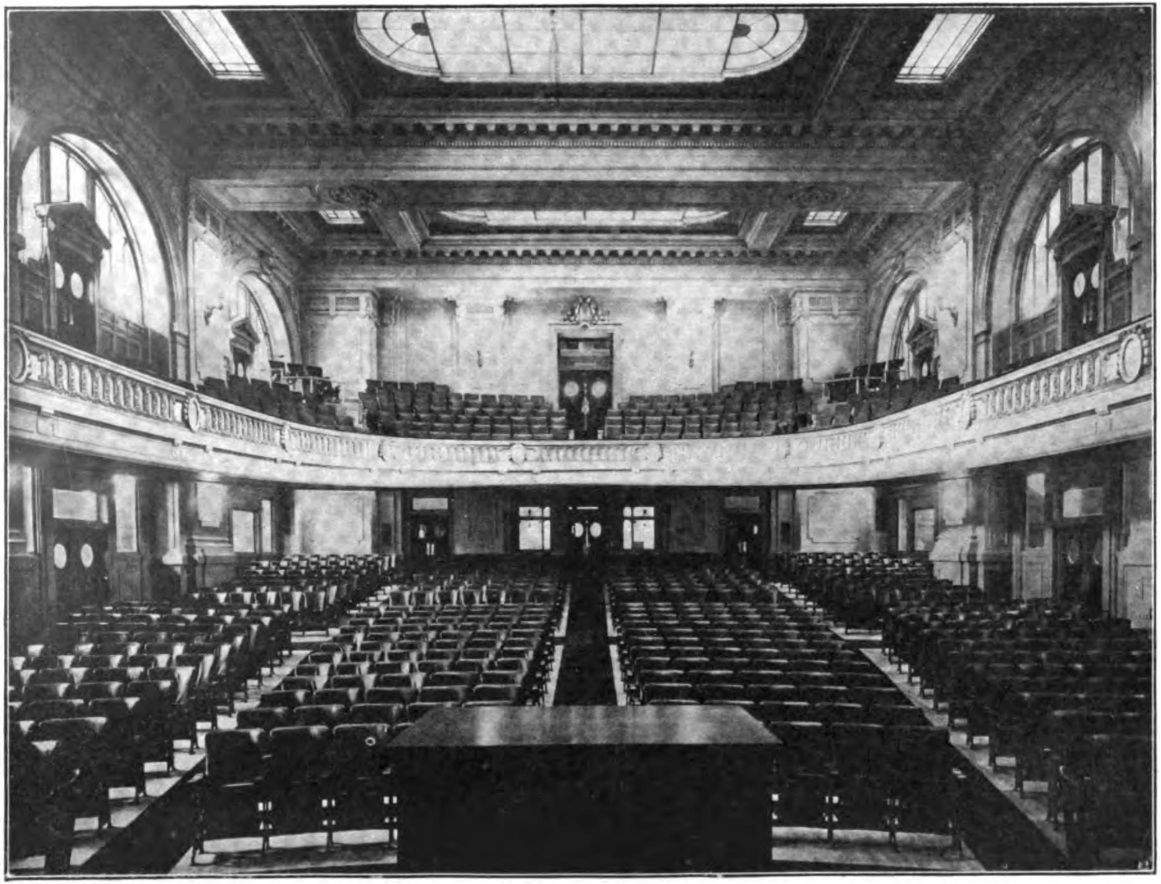

The Auditorium of the Engineers' Building.

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PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

Published monthly at 33 W. 39th St., New York City, under the supervision of

THE EDITING COMMITTEE,
THOS. J. JOHNSTON, Chairman.
GANO DUNN. CECIL P. POOLE.

RALPH W. POPE, Editor.

Subscription. United States, Canada, Mexico and Cuba. $5 per year.
All other countries $6 per year.
Single copy 50 cents.
Subscriptions must begin with January issue.

Advertisements accepted from reputable concerns at the following net rates:

Space.	Less than half year. per issue.	Half year. per issue.	One year. per issue.
1 page	$36.00	$32.00	$30.00
½ page	22.00	18.00	16.00

Additional charges for Preferred Positions.
Professional Cards, special rate of $25 per year.

Vol. XXVI. **April, 1907.** No. 4.

The Fiscal Year

THE financial year of the Institute begins on May first, at which time the annual accounts are closed, and the balance sheet prepared for presentation to the Board of Directors and the membership generally through the annual meeting on May 21, 1907. At this time the bills of the members are presented, and if promptly paid, much time and trouble will be saved in the accounting department. It is the universal practice of voluntary organizations to require payment in advance, and where this is the rule it should be complied with. Every member should appreciate the value of system, and it is noticeable that a large number pay all their current bills about the first of each month. There are others, however, who appear to file them away so successfully that they are lost sight of altogether, and they may be paid upon receipt of a statement some months later. This is not a serious matter so far as the treasury is concerned, but eventually when desk-clearing becomes urgent the original bill is resurrected and a second payment is occasionally made. To avoid cancellation, this second check is placed to the member's account as an advance payment. There are now over five thousand accounts upon the Institute's ledger, and it is therefore important that every one should do his part toward lightening this work as much as possible. Many students have been lax in meeting their payments, and have expressed their dissatisfaction because their names have been dropped from the list. It should be understood by all, that successful business management cannot be expected unless proper attention is given to the smallest financial details. Those members who wish to avoid the annoyance of receipt and payment of annual bills may compound their dues by making a single payment of two hundred dollars. There is now no question about a life membership being a good investment, especially to Members who pay an annual subscription of fifteen dollars. The equity of the Institute in the Engineers' Building is about $500,000, and this investment in itself gives an assurance of permanency which has not previously existed.

Engineering Experience

ONE of the requirements of the Constitution is that a Member shall have had at least four years of electrical engineering experience. A proper interpretation of this clause is rendered difficult in many cases due to the vague manner in which an applicant's record is prepared. There may be for instance, no indication as to whether he actually did the work, or whether he was associated with some other person. It may appear that he simply ordered machinery of a specified capacity which was designed, manufactured and installed by the engineers of the company to which the contract was awarded. A

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clearer view of the conditions may possibly be obtained by considering the qualifications of an architect who has been retained to build an ordinary dwelling house. His client may supply him with certain necessary essential details as to cost, material, and location. He may also indicate the number of rooms, their general arrangement, his choice of heating and lighting systems. He may be sufficiently skilled as a draftsman to prepare a satisfactory plan of the house. The architect would then embody all these suggestions in the working plans, and would prepare the necessary specifications, so that the builders could make their tenders for the structure. In a case of this kind, while certain general ideas might be supplied by the owner and the builder, there could be no question as to the functions of the architect. Even if all the details had been handed over to his office assistants, he was the responsible man, and his prior experience had been such that he could personally have done the work.

There is an underlying principle upon which the requirements for transfer are based. It is the intention that it should be in the nature of a certificate that the applicant is fully qualified to practice as an electrical engineer in that particular branch of the profession in which he is understood to be an expert. It should not be expected to give a man prestige which he is not actually entitled to by reason of his skill, training and practical experience which has rendered him competent to "design as well as erect electrical engineering works."

Parallel Sessions

ONE of the important features of the Engineers' Building, which was planned for future contingencies, is the provision for simultaneous meetings, or separate sessions of a single meeting. An opportunity to test an arrangement of this kind occurred on April 26. One session was devoted to electric lighting, and the other to telephone practice, which might naturally be expected to make a distinct division in the audiences. This proved to be the case, and it points to the possibility of meeting a future demand for the presentation and discussion of a greater number of papers during a single season, and also taking up subjects which have in the past been crowded out by reason of the abnormal interest in a particular phase of electrical engineering. Through the possession of facilities which have not heretofore existed, it appears to be possible to meet every emergency, and experience has already shown that telegraph and telephone engineering which may have been considered as branches of the art which have been neglected, will yet take rank in importance with high power development. The Institute, as well as most other similar organizations, has been hampered by the lack of suitable facilities for meeting the marvellous growth of the industry. With the beginning of another season it will be in a position to surpass its previous records, and make still further claims for the universal support of the profession.

INQUIRIES regarding various investment schemes continue to come to this office. Nothing of this kind has been or will be endorsed by the Institute. The Institute lists are printed and are available for use in addressing circulars. Members should exercise their own discretion regarding these alleged opportunities to increase their wealth. They may or may not be worthy, but any attempt to obtain capital in this manner is open to suspicion.

THE ballots on the revised Constitution of the Institute have been coming into the Secretary's office in large numbers during the latter part of April. As we go to press there have been over 2400 received and there is, therefore, every indication that the new Constitution will be adopted. The last day upon which valid ballots can be received is May 9.

Dedication of the Engineers' Building, New York, April 16-17, 1907

TUESDAY, APRIL 16, 1907, AT 3.00 P.M.

In the presence of a large and distinguished audience composed of men eminent in the scientific world, in public life, in educational work, in trade and transportation, and in all branches of professional engineering work, the Engineers' Building was formally dedicated on Tuesday afternoon, April 16, 1907. An account of the dedicatory exercises follows:

Music. Largo, Handel. The Richard Arnold double sextette.

Opening by Charles Wallace Hunt, past-president, of the American Society of Mechanical Engineers, presiding officer.

CHARLES WALLACE HUNT: On the eighth of May, 1906, Mrs. Andrew Carnegie laid the corner stone of this building. She has graciously presented to the United Engineering Society the setting maul that was used by her on that occasion. The historic event in which this implement took part, and Mrs. Carnegie's graceful act in placing it henceforth in our care, makes it an especially precious object to us. It will hereafter be used by the presiding officer of the meetings held in this auditorium. As a gavel, its voice will now be heard for the first time in calling this dedicatory meeting to order.

Prayer by Edward Everett Hale, D.D., chaplain of the United States Senate.

Communication from the president of the United States.

THE WHITE HOUSE, WASHINGTON, D. C.
April 13, 1907.

I heartily congratulate you on the opening of the building of the Engineering Societies. The building will be the largest engineering center of its kind in the world. It is indeed the first of its kind, and its erection in New York serves to mark and emphasize the supremacy which this country is steadily achieving through her proficiency in applied science. The whole country is interested in the erection of such a building, and particularly of course all of those who follow either the profession of engineering or any kindred profession; and in no branch of work have Americans shown to greater advantage what we like to think of as the typically American characteristics.

With all good wishes, believe me,
Sincerely yours,
THEODORE ROOSEVELT.

Communications from the president of the Republic of Mexico and the governor-general of Canada.

CHARLES WALLACE HUNT: The dean of the engineering profession in America, Charles H. Haswell, now in his 97th year, hoped to be with us this afternoon. We have this letter from him:

324 West 78th Street, New York.
April 16, 1907.

I regret my inability to be with you this afternoon. An attack of the grippe has held me at home for a month. Please submit this excuse to my much honored friend, Mr. Carnegie.

Sincerely yours,
CHARLES H. HASWELL.

CHARLES WALLACE HUNT: There have been several prior attempts to bring the national engineering societies into closer fraternal relations, but each was without tangible result. In December 1902, Charles F. Scott, then president of the American Institute of Electrical Engineers, in a public address happily voiced the aspirations and the hopes of the progressive engineers who had so long worked in various ways towards a common end. He pictured before his audience:

"A magnificent building, the Capitol of American Engineering. Into this home, situated in the metropolis of the nation, are gathered the great engineering societies from their scattered lodgings."

In his vision, he there saw a great technical library, ample assembly halls, comfortable parlors, and also the headquarters of a score of lesser societies restricted in their scope but affiliated in their work.

Two months later, a dinner to celebrate the founding of the library of the American Institute of Electrical Engineers was given in New York. Mr. Carnegie after having four times refused Mr. Martin's invitation, accepted the fifth and attended the dinner on February 9, 1903. At this meeting Mr. Scott voiced again the oft-expressed wish that the national engineering societies could join hands to the end of creating a great technical library, coöperative society work, and a suitable headquarters that would furnish ample accommodation for themselves and for many kindred societies.

Mr. Carnegie was an interested listener to those addresses. His interest was not impulsive or ephemeral. The following day he invited Mr. Scott and Mr. Rice to call at his home in Fifth Avenue. The events following this fruitful conference will now be presented to you by Mr. Scott, who has been the tireless chairman of the joint Conference and Building Committee from its organization four years ago to the present time. This large committee with its nearly one hundred regular meetings, and the expenditure of one and a half million dollars in this movement, by ample discussion, came to a full agreement on every subject, important or trivial, and for the entire four years adopted every resolution by a unanimous vote.

Historical Address

BY CHARLES F. SCOTT

The realization of the ideals of many years and the definite beginning of the building which we to-day dedicate dates back four years. On February 10, 1903, Mr. Carnegie talked over the project with the two gentlemen whom he had invited to his house. As the general scheme seemed feasible, he said that he was ready to provide the funds for a building if a practicable plan could be presented. An hour later, a meeting of engineers had been arranged for the following day. The scheme was discussed; plans were formulated, and a few days later, John Fritz, William A. Redding, Calvin W. Rice, Chas. F. Scott, John Thomson, and our lamented friend, John C. C. Kafer, discussed the matter freely with Mr. Carnegie. To us, on St. Valentine's day, in the late afternoon, he said the magic word which transformed long-cherished dreams and new-found hopes into a reality.

And here about us is the culmination—the work of committee and architects and builders. The building stands as its own record of what has been done. The result is simple and easily seen; yet it embodies the solution of many problems. At first it seemed that so much was achieved when the funds were provided that little remained to be done. But much has intervened between the making of the gift and completing of the building.

In designing the building we had no precedent to follow, for never before had engineering found so generous a patron. Engineering societies themselves belong to the new order of things. The oldest of the participating societies numbered little more than three decades. In the past these societies were well-nigh strangers to one another. Now, to utilize this gift, they must plan and work together. The gift, moreover, had a unique feature in being presented in common to professional societies, whose interests are technical, and to the Engineers' Club, which is social.

At the beginning there were broad questions of general policy to be determined. There must be a basis of relationship between the professional societies, and then one between the societies and the social club. As the outcome of this first step, three members from each of three societies and three from the club were appointed as a conference committee of twelve members. Through its two sub-committees, the two buildings with convenient intercommunication, have been erected on land acquired respectively by the societies, acting through the United Engineering Society, and by the club.

The building for the engineering societies required first of all to be planned in imagination. What were the immediate needs of our three societies? How many associate societies would join us, and what were their needs? What should be the size and number of assembly halls; the provision for offices, for board rooms and reception rooms and library? Even though we gauged the present accurately, how should we estimate future needs? What of future growth? So rapid is the present growth that the aggregate membership of the three founder societies has increased fifty-three per cent. since the gift was made. New engineering societies are forming.

It would be interesting to relate, if time permitted, how our ideas developed, so that a million dollars was too little, and Mr. Carnegie graciously made his letter read: "Say, one and a half million;" how our ideas crystallized into a program to be followed by competing architects; how we selected from twenty-six sets of plans the one which all agreed was best; how we studied the details of arrangement and the selection of materials to secure flexibility in the functions of the various parts of the building, and insure a wise expenditure of the funds entrusted to us; and how efficiently architects and builders have done their part.

We recognized that an underlying purpose of Mr. Carnegie was to develop the human as well as the technical side of the engineering profession. He said to us that cooperation is "the keynote of success" and that there is "a harmonizing feature which counts for everything in the progress of any great movement, political, social or scientific." Hence he associated together the club and the societies in order, as he expressed it, "to combine the social with the scientific."

The same idea has guided the arrangements of the societies' building. It is seen in the spacious entrance hall, in the corridors about the auditorium, in the reception rooms of the societies, in the arrangement of the smaller halls by which the one used as a lecture room may have an adjoining one as reception room, and in the provision for serving light refreshments which add zest to the social after-meeting.

And, then, in a sense, the crowning feature of the whole project, as it is of the building itself, is the library. In the magnificent spaces which are above us there lies a great possibility. The libraries of the three societies are the nucleus, the foundation for a great engineering library, a depository for archives, a record of experience and achievement, a storehouse of intellectual power of countless value and far-reaching influence. In the future it may be embellished and dignified by memorials of those who have contributed to the engineering progress of the world. And, in this library, the past officers of the societies have already placed a bronze bust of the donor as a perpetual recognition of the great gift of this building.

And this building—simple, dignified, and appropriate to its intended uses—is to be the home of the engineering societies.

These societies are the expression of engineering forces, and engineering forces are fundamental to the achievements of our age. Underlying the tremendous economic changes ot the present times is the power-generating steam engine. Driving the locomotive, it has transformed innumerable provincial towns into one great community, and many independent states into one nation. Driving the factory, it has developed manufacturing and industry on a scale undreamed of a century ago, and scarcely comprehended now. Driving the ocean vessel, it is rapidly making the whole world kin.

Its influence transforms and vitalizes. The present production of wealth, the new functions of capital and labor, the modern business corporation, the occupations and social relations of men, the interdependence of nations, the growing brotherhood which portends a universal peace—all have followed the engine of Watt, all belong to the "new epoch," the epoch of manufactured power.

The whole fabric of our daily life is based upon the modern methods of utilizing the materials and forces of nature; it is reared upon foundations laid by the engineer; it daily depends upon the operations which he controls. It is he, it is the engineer who has been the harbinger of prosperity and of peace.

Progress continues. See for example what electricity has accomplished within our easy recollection! Yet we scarcely realize it unless for even a single day we have no telephone, no electric light, no street car. The growth of the telephone in its first ten years is exceeded by the present growth of a single year; the output of all the electric central stations at the end of the first ten years is exceeded by that of a single station to-day.

But I am merely repeating what we all know. I simply ask you to realize that the engineer has been foremost in bringing about our present civilization, and that to him new and larger problems are continually presented. Not only to the quantity and the difficulty of his work increase, but it even promises to be of a new quality. With the twentieth century there begins a "new knowledge" in science; from it there may soon follow a new engineering.

These increasing responsibilities demand that the most efficient methods be found. The characteristic of the modern method of large accomplishment is coöperation, by which men act not as individuals but in concert. Years ago each engineer was apt to work by himself; technical knowledge and experience were kept secret. Stagnation resulted. Through intercourse of knowledge and interchange of experience progress came, and in those branches where discussion has been most active, progress has been most rapid. The engineering society has become the clearing-house for knowledge and experience. And herein is the great purpose of this building. It is now the instrument of coöperation among engineers. It enables these societies to become more useful in the dissemination of knowledge, in the training and developing of men, in the cultivating of high ideals, and in making the engineering profession more efficient in its great task of making this world a better place to live in.

The significance of this building is not in the past, nor in the present, but in the future; for the vitality which has prompted engineering development in the past is unabated now, and will continue with increasing force in the future. Witness this event, a gift of a million and a half for building, supplemented by a million more, the largest investment for engineering in the history of the world. Witness, too, this audience of a thousand men, representative of science, engineering, education, literature, art, and government, gathered with sympathy and joy to bid Godspeed to the work we here inaugurate and acclaim this day the beginning of a new era in engineering.

Mr. Carnegie, it has been your great privilege to make this possible. You provided money; it has been transformed into bricks and mortar. But your letter gives more than money, in it is an ideal, "A union building for you all;" that, too, has transforming power; already the "harmonizing feature" is an active force, our societies are working together, they are getting a broader view of their position and new inspiration for the large work which lies before them.

As we were leaving your house on the day you made the gift, Mr. Fritz lingered a moment. When he overtook me he told me that he had said to you, "Mr. Carnegie, the day will come when this gift will be looked upon as one of the wisest and most useful you have ever made." And I am sure I voice the sentiment of this audience when I say that John Fritz was right.

Charles Wallace Hunt: To Mr. Herbert D. Hale, architect, and Mr. H. G. Morse, associate architect, we are indebted for the architectural beauty of this stately edifice. To their ability in grasping the desires of the committee, and skill in working these desires into a harmonious building, without and within, the whole engineering profession is their debtor.

Under their skilful guidance this engineering home has been erected within the amount of funds first assigned for the purpose, and occupancy commenced a few weeks after the builder's contract time had expired. It is a pleasure for the building committee to report deliberately that in the design and in the erection of this building no differences have arisen between the committee and its architects, and no compromises or makeshifts of any character have been permitted in the execution of the work.

This gift to engineering, which we now dedicate, is not only, nor even principally, the presentation to the founder societies of this material building. Immeasurable benefits will also flow from the orienting of the minds and directing the energies of engineers into more effective coöperative work.

Mr. Olcott, acting in behalf of the founder societies, I present to you the key of this building which is now placed under the administration of yourself and your successors. We confidently trust that under your fostering care the library will develop into one of world-wide influence, and be as an ever helping hand, freely extended to any person who seeks help from the experience of those who have gone before.

We have an abiding faith that it is not engineers alone that is benefited, but that the world itself is a better abode for man because of Mr. Carnegie's great donation. We fondly hope that this home of engineering under your guardianship will ever be freely open to whatever will bring purer aspirations, nobler ideals, or more fruitful lives to the generations of men who will come after us.

Address by E. E. Olcott

It seems to me, Mr. Hunt, as if this key with which you honor me, as president of the trustees of the United Engineering Society, were the key of the whole engineering situation. It is suspended by the red, the white, and the blue—a color for each of the three founder societies, the three together forming a perfect union fittingly representing all the associate societies and standing for the engineering profession. May these all, without any loss of individuality, nevertheless form a grand enduring whole which shall typify the national federation of our states, and may our individual engineers shine as do the stars on the blue field of our country's emblem. In this union there is strength. This key opens the great bronze doors of knowledge, of usefulness, and of accomplishment, and the building thus opened and dedicated is one of the world's greatest storehouses of the records of engineering achievement. It shall be the trysting place of the guilds that plan the physical progress of the world. The great library which crowns it is already one of the most complete technical libraries in existence, especially along mechanical, mining, and electrical lines. When we can secure an adequate endowment, it will become even more important. It is happily situated within a stone's throw of the new public library, which it is bound to supplement on engineering subjects. It is open for the benefit of mankind. This key stands, then, for freedom, coöperation, and the open door. With it we can unlock some of nature's hidden secrets.

The currents of electricity have played around the world for all time, but only recently has the engineer harnessed them in the service of man. The iron ores have been in the everlasting hills since the creation, but only recently has the engineer been able to fashion the steel into the mammoth structures, the bridges, the railways, and the tunnels.

The engineer should be the altruist, content to seek not so much his own as the world's achievement. We cherish, then, the gift of the benefactor, a man whose very fortune is an exponent of "united engineering," and whose gift to us most truly embodies the man's own life, and perfectly supplements in this metropolis, his great Institute dedicated last week at Pittsburg. Neither he, nor we, can live to see the good that this building will do, emphasizing as it does the strength there is in unity, that, through coöperation and the publication of the results of scientific research, we are helping to advance the progress of the world.

In all Latin countries, the key has the most sentimental significance, typifying the love of the man for the woman of his heart. What engineer worthy of the name has not as much glamor of love for his profession as for his sweetheart? And so, Mr. Hunt, in the name of united engineering, with this key as a token, "we plight thee our troth," and pledge, that by so much as in us lies we will carry out the ideals of the munificent donor and of all who have contributed for the land on which this noble pile has been erected.

CHARLES WALLACE HUNT: At an early conference with Mr. Carnegie, the business in hand being disposed of, the members of the committee, as they were preparing to leave, were conversing with him on various subjects foreign to the occasion of their visit. Mr. Carnegie mentioned his lively interest in the project of erecting a modest memorial to James Watt. In closing he remarked: "I do not believe in expending large sums on monuments," then turning a little aside from his guests, he threw his left arm caressingly around an imaginary object, and pointing to it said in a low soliloquizing tone, "What I do believe in, is something with a living soul in it."

This chance remark deeply impressed his auditors. Something with a living soul in it, seemed to them more than a building, more than rooms without a rental. In imagination they saw a grand engineering building, and dwelling within it an ever-living soul of helpfulness to us and to our successors. In their vision, they saw this living soul developed into a potent world-force constantly working as the centuries pass, for the elevating of everything in our civilization that depends on the life and the work of the engineer.

To make this fleeting thought a reality, and develop the idea into an ever-living soul, the committee would have to undertake a task far greater than the erection of a building. It would be the erection of a building, plus the embodiment of this vision. Instead of a gratuity to a few societies, it would become a gift by Mr. Carnegie to engineering in its broadest sense. Unanimously, the committee adopted this broad view and diligently bent its energies to work out this double task, as the way opened. The committee has terminated its labors and now presents this building as a worthy home for that living soul whose contemplation animated the mind of its donor and inspired the recipients of this great gift. I present Mr. Andrew Carnegie, donor of the building.

Address by Mr. Carnegie

The Scotch have a saying, and they have many wise sayings, that fools and bairns should never see a thing half done. I don't wish to associate myself either with fools or bairns, but I think I may add that donors should never see a thing half done. I went to Pittsburg the other day knowing nothing of what I should find; I had sedulously kept away from the fairy palace that they were erecting; I knew nothing nothing of it, but when I got there I found a palace that Aladdin might have brought forth and so beautiful that I felt that I was in a dream. I come here to-day under somewhat similar circumstances, and am brought into this beautiful hall exquisite in every part, and face to face with this splendid audience. Well, it gives point to what Mrs. Carnegie said when I was expressing to her that I was totally unable to realize what part I had taken in creating a palace; I said to her I felt like Aladdin rubbing the lamp, and she said, " Yes, and we didn't even have to rub the lamp." But as the proceedings went on at Pittsburg and I had the great pleasure of addressing those there present and showing the audience who had created the palace, this thought occurred to me: it is the spirit with which men are enthused that does the work: the sense of coöperation and the realization that really the performance of great and benevolent work raises the men that participate in it far beyond any personal work for themselves.

The safety of human society lies just here. Whenever men coalesce to do some good a unification takes place and a consolidation; and whenever men meet to conspire against the public good to do some evil, they find themselves unable to trust each other. Segregation takes place and they fail. That is the reason why you needn't lie awake nights and worry about the future and about what problem society is going to meet. As sure as the sunflower turns towards the sun and receives its light and heat, just as surely human beings march onward and upward with their faces to the sky to do better things.

Much that I was taught in my youth has passed away; much that I once thought of I have had to discard: but here is the rock upon which I rest and meditate and find happiness. Nor can you deny this, that quite apart from whatever evil exists, there is that principle of improvement inherent in us. To-day is better than yesterday and to-morrow will be better than to-day. So I look forward to the future of this building, and I know that the organizations to whom it is devoted will advance and continue to meet the developing needs of the age, as the years roll by. That is comforting, that is encouraging, and that is a reflection to which I shall always return and upon which and in which I shall always find rest.

I congratulate you upon your architects. This architectural selection was just in accordance with my ideas. I have never given a building in my life that I could control except by competition; I don't want names of architects, I don't want everything that an architect may present, for human Homer nods and the dead past nods even; I want to see what a man brings and I don't want to see what his name is or to know his name. There were twenty-six plans submitted, as you have been told, and there was a committee to pass upon them, and then there was a very wise and good man as a sort of censor over the plans, Professor Ware, and he chose two plans—one for the Engineers' Club building, and the other for this building as being the best, and, by the way, the committee had previously agreed upon those two plans. Well, who were the architects—some well-known, great firm? No. They were two young men that had never been heard of in New York, I think. There is the proud father of one of them (here Mr. Carnegie turned to Dr. Edward Everett Hale and bowed) and there is a lady sitting up there (pointing to Mrs. Carnegie, who sat in the balcony) who is also proud, for the other successful architect is Mrs. Carnegie's brother.

Not one member of the committee knew whose plans were selected. Well, gentlemen, that is triumphant democracy. No pedigrees, no social influence, count for much in the architectural profession. Nothing but real merit. And the engineers who acted were true to the principles of their profession. The engineer works from morning until night unvaryingly for what is true. Two and two make four, and one five all the time. That gives the engineer his character. No fraud, no deviation, no evasion; but march, march, march, true to the line all the time.

I wish to speak of one remark that the President makes about American characteristics, and you also, Mr. Hunt, have spoken of my reference at the foundation stone ceremony to the spirit of union and coöperation. One of the great advantages which the American has over the man of any other country lies in his ability to coöperate and his disposition for coöperation. Our political institutions which make every man the equal of any other man, every man's privilege any other man's right, lies at the foundation of that characteristic. Americans all meet upon a plane of equality; one man is just as good as another man, and therein he meets others in a sense of brotherhood, and the committees that you hear about acting by a "unanimous vote" is the outcome of that. I venture to say there never was a case like that with the Britons or the Scotch, especially with the Scotchman.

"Where are you going, Sandy?" said one Scotchman to another.

"Doon to the club," said Sandy.

"An' wha' foor?"

"Just to controdeect a wee."

That is the way it is over there. Now, the American with his political institutions, with the blending that he has in him of all nations, is a man who partakes of the best quality of each of the other nations. It is from this fact that you reach coöperation, and I speak with great experience, knowing manufacturers and engineering societies on the other side, every one of them standing apart and unable to get together, and here the Americans calmly sit down and discuss and coöperate and evolve. If there be any guests here from the other side—yes, I see there is one (pointing to Sir William H. Preece)—I think he will carry home with him from what he heard in Pittsburg—for there was a similar story there, too—this impression, and that he will say, "Well, these Americans begin even in business to feel more of the spirit of equality and brotherhood than we do."

We only hate those we do not know, is quite true. That is my experience. The older I get—no, I mean the younger—and the more experience I have with men—and with women—the more I am convinced of the truth of the fact that you only have to know the virtues of your fellow men to find that they are all brothers. That is the reason that I am a great advocate of the peace of the world. It isn't enough for individuals to feel the spirit of brotherhood as all Americans do, but we must enlarge it and realize the great truth, that all men of all nations are really our brothers.

I have no more to say to you than again to express my surprise that the little conversation that Uncle Fritz and these gentlemen and myself had has resulted in such a magnificent building as this, and more than that in proving to the world that the engineering societies of America are one band of brothers with headquarters here to which every one of them is loyal. I thank you very much.

Music. Träumerei, Schuman. Cello solo, Kronold.

Charles Wallace Hunt: This twentieth century promises to exceed all preceding ones in the rapid, almost tumultuous, advance in the arts and sciences. Engineers are largely engrossed in the investigation of specific problems and in the constructive work of this great movement. There are, however, gifted persons in this century's work who have raised themselves to an elevated position, on a mountain top as it were, from which they can clearly survey this great field of action. With quickened perceptions and trained intellects, they can bring to us tidings of surpassing interest as to whitherward we are traveling.

We count ourselves especially fortunate in having the privilege of hearing, as orator of the day, one whose exalted position gives him a clear view of the whole field of human endeavor. Your chairman presents Arthur T. Hadley, President of Yale University.

The Professional Ideals of the Twentieth Century

By Arthur Twining Hadley

A building like this is the best monument of what the twentieth century has accomplished. The really important part of the history of a nation is the development of its ideals and standards. The specific things that it does are important not so much for their own sake, but for the sake of the evidence they give as to the trend of a nation's thought. It is not the magnitude of the individual battles which makes a war worth reading about. It is the ideas under which the war is conducted and the constitutional principles for which it is fought. It is not the census figures which decide whether a nation is great or small. It is the industrial methods and educational ideas which these census figures indicate. And in like manner it is not the buildings and machines and railroads and mines which constitute the important part of the history of the engineering profession. A book might give a good description of a thousand of these great engineering works, and yet fail of being in any sense a true history of engineering progress. The thought of the successive builders and the influence of that thought upon the conduct and ideals of other men are the things that we really care about. The story of the concrete achievements that have dazzled the eye of the world is but the unimportant and superficial part of the history. The real thing for which we care, the thing that helps us to understand the past and inspires us with hope for the future, is the story of the men who did the things—their struggles and their discoveries, their trials and their successes.

The men who did more than anything else to make the nineteenth century different from the other centuries that went before it were its engineers. Down to the close of the eighteenth century the thinking of the country was dominated by its theologians, its jurists, and its physicians. These were by tradition the learned professions; the callings in which profound thought was needed; the occupations where successful men were venerated for their brains. It was reserved for the nineteenth century to recognize the dominance of abstract thought in a new field—the field of constructive effort—and to revere the trained scientific expert for what he had done in these lines. Engineering which a hundred years ago was but a subordinate branch of the military art, has become in the years which have since elapsed, a dominant factor in the intelligent practice of every art where power is to be applied with economy and intelligence.

A building like this is therefore the symbol of all that is most distinctive in the thought of the century that has gone by. A hundred years ago we might have had a building in honor of theologians or of lawyers or of physicians; but one that symbolized the achievements of the engineer was beyond man's dreams, because the world at large had neither felt the need of his work, nor dreamed how soon it would be seeking his leadership.

I have spoken of this building as a monument; but that is after all not the proper word. A monument implies that a man is dead, or at any rate that he has so nearly reached the limit of his growth that he might just as well be dead. Looked at in this way, the engineering profession wants no monument. It has not yet reached the limit of its growth. It has not come to the time when a complacent survey of the past will take the place of toilsome planning for the future. Not a headstone do we want, but a milestone—a point at which our measurement of what has been already done, serves as an inspiration for the journey yet to be traversed. We may take this opportunity for a brief review of what has been done in engineering and other allied professions; but the engineer who is worthy of his calling will value that review most highly, if it is made a means of calling his attention to that which yet remains to be done.

A hundred years ago there was a sharp separation between scientific theory and commercial practice. There was not a great deal of science anyway, outside of mathematics and astronomy; and what there was was underrated by men of affairs. In those days when a man said he was practical it meant that he was not theoretical; that he didn't know science, and didn't want to know it, and didn't want to have any man around that did know it. The men of that day trusted to two guides; inherited prejudice, and individual experience. The more enlightened among them used experience to correct prejudice; the rank and file of them used experience to reinforce prejudice; and that was about all the difference. The value of generalizations, except in religion and in statecraft, and in some few branches of medicine, was not recognized by anybody.

The great element of progress in the nineteenth century has been the recognition on the part of mankind in general, of the value of scientific generalizations in every department of human conduct. Our science has become sounder, our understanding of its applications clearer, and the public has recognized that scientific conduct of a business means the substitution of universal experience, learned with difficulty and applied with toil, for the narrower range of individual experience which was at the disposal of the so-called practical men of fifty or a hundred years ago. Of this change the engineer is the representative and the leader. He it is that makes physical science in its various lines applicable to the complex problems of construction and development. He it is who has paved the way for the recognition of the technologist and the expert in every line of human industry. He it is who has shown how mathematics, instead of being an abstract discipline, remote from every day human affairs may become the means of applying truths for a long time remote and undiscovered, to the every day affairs of the world in which we live. Not the buildings that you have built, gentlemen; not the railroads that you have planned; not the machines that you have invented, represent your greatest achievement. Yours is the proud boast of having in one brief century established science as the arbiter of the material affairs of mankind, and of having enforced her worship upon a world once reluctant, but now gloriously admiring.

Well, then, you will ask: is there anything which remains to be done comparable in importance to this? Yes, there is. An equally large part —perhaps in one sense a much larger part— of your professional duty yet remains to be accomplished. It is not enough to have technical training. It is not enough to know the special sciences on which the practice of a profession is based. A man ought to have clear conceptions of the public service which his profession is based. A man ought to have clear conceptions of the public service which his profession can render, and the public duty which its members owe. Thus, and thus only, can the engineer, the lawyer, the physician, or a member of any other learned profession, rise to the full dignity of his calling.

For there are two quite distinct qualities which must be combined in order to secure the best professional services; two quite distinct tests which work must meet in order to be pronounced first class. One of these is the technical standard; the other, for want of better word, may be called the ethical standard. The man who wishes to build a good railroad must not only lay it out according to the rules of the surveyor's art, with proper curves and grades, and bridges which will not fall, but he must also have intelligent regard to the needs of the population, the safety of travel, and the many other factors which determine whether a railroad shall be a work of public use or a source of industrial bickering and financial disaster. This combination of public and private demands is not peculiar to engineering. It can be illustrated in every other profession of importance. It is not enough for the lawyer to give advice which shall be technically sound, and which shall enable his clients to keep out of jail. He must learn to take a large view of the law as a means of public service instead of private gain. It is not enough for the physician to know how to cure specific diseases. He must know how to care for the larger problems of public health, and to use the resources of the community in a way to meet as fully as possible its sanitary needs.

This larger view of professional obligations is not so fully recognized as it should be. We have in the nineteenth century made so much progress in the technical training of doctors and lawyers and engineers that we sometimes forget that there is need of anything more than technical training. We have let the old idea of public leadership, which was prominent in the minds of the great professional men of past centuries, give place to another and narrower ideal which is fully satisfied when a man has made himself a technical expert. Many a man of real eminence in his calling deliberately rejects the wider conception of professional duty which I have here indicated. Perhaps he recognizes the claims of public service; perhaps he does not, but in any event he believes that these claims rest upon him as a man rather than as an engineer or a lawyer. In his professional capacity he says he is hired not to tell what the law ought to be, but what it is; not to advise how a railroad can do the most public service, but how certain men with certain ideas of their own can best use the differential calculus to get these ideas carried out. This is perhaps the prevalent view of professional ethics to-day. I believe that it is a wrong view, which must menace not only the influence and standing of the professions themselves, but the general interests of the republic.

In the first place, a man who believes that he is hired to carry out another man's ideas can never claim a position of actual leadership. He remains a paid servant—highly paid, doubtless, because he is possessed of a kind of skill which is very unusual, but nevertheless a servant, bound to carry out the wishes of his master. A group of professional men which regards this as a proper view thereby forfeits the claim to stand in the first rank socially and politically, and voluntarily accepts a position of the second rank. I do not believe that the engineers of America want to do this. It has been said that engineering is the handmaiden of commerce; but I do not believe that the men who have planned and dedicated this building will be satisfied with any handmaidenly conceptions of what their successors ought to be. If for a moment, in our zeal for new technical developments, we have let our responsibilities as public servants fall out of our hands, I feel sure that we shall be ready to take them up again as soon as our eyes are opened to the real situation.

For mere technical achievement is not the thing that endures. Among the peoples of the ancient world, I suppose that there were no engineers equal to those of Egypt Considering the means at their command, the things that they did were absolutely extraordinary. They did some things which, even with the means at our command, we can hardly duplicate. But they used their abilities in the service of a dominant priestly caste; and therefore, while their work fills us with admiration, it does not appeal to us as does the work of the Roman engineers a few centuries later, who built roads and aqueducts and bridges, and thus took the lead side by side with the Roman lawyers in establishing the basis of modern civilization. The roads and bridges of Rome, simple and straightforward as they are, constitute a more enduring monument to the Roman engineers than all the obelisks and pyramids that were ever erected.

For their own sake, then, and for the sake of the enduring quality of their work, we can appeal to the engineers and lawyers and physicians to see that it is adapted to public ends. We can reinforce this appeal by a yet stronger one on behalf of the American commonwealth as a whole. For the development of technical ideals and standards in our various professions during the last few centuries, to the neglect of exclusion of ethical ones, is constituting a very serious public danger.

A commonwealth like that of the United States is necessarily governed by public opinion. Courts may formulate this opinion. Legislatures may pass rules to give effect to it. Police may enforce its demands against the recalcitrant. But the governing power rests in the intelligent public opinion itself. When that opinion ceases to be intelligent and powerful, freedom becomes a mere name. Now, a serviceable public opinion of this kind can only be formed when intelligent people, technically trained for different lines of life, seriously try to find out how their work can be made to meet the public needs. They are the only ones who can do this well. If it is done by anybody else it will be done badly. If the lawyers as a class try to keep the law in line with the demands of intelligent public opinion, we can get good law. But if lawyers are content to see the law perverted to private ends, and judges take refuge in technical construction of precedents, without full regard to the needs of the existing situation, legislatures will step in to create a chaos of conflicting laws which are worse than no law at all. In like manner, if our engineers get their own minds clear, and get the public mind clear, as to the political economy of the properties entrusted to their charge and the ethics of their management, they can forestall these conflicts which now threaten to break out at every moment. But if the members of a profession whose advice is necessary is order to a clear understanding and wise settlement of these problems retire from the field of action, the matter will be settled by those whose interests are more selfish and less farsighted. There are three professions to-day which do not regard themselves as servants, but as masters—the financier, the journalist and the politician. If the engineer and the lawyer accept positions as servants, simply putting their technical knowledge at the disposal of merchant, journalist, or politician who will pay the highest price for it, it is not simply a confession of inferiority, it is a dereliction
duty.

Do you say that it is impos
single man or a group of men t
these evils? Look at the
Albert Fink, who in 1874,
was an engineer on the Lou
Nashville Railroad, made a
the cost of transportation
been at the basis of all the
management of the traffic d
of railroads from that time

Of course, Albert Fink v
man. He could do things
of the rest of us cannot. B
believe, that if our profe
awake to the necessity of broad ideals like those of Fink the greatest dangers

which threaten the American commonwealth would be fairly met, and the men who met them would be given the position of power and trust which they had proved themselves worthy to hold. Nobody is satisfied to-day with the struggle between individualities and socialism, between financier and politician, between Wall street and Washington. The men who are engaged in this conflict are for the most part heartily sick of it. Let a man or group of men arise who add to their technical knowledge, a readiness to use that knowledge in the public service, and people will be ready to put them in charge of affairs and follow where they lead. We have outgrown the day when a little common sense was sufficient for managing the affairs of the nation. They are become too complex; and this complexity gives the engineer, if he will add to his training in mathematics a training in ethics and political economy and the fundamental principles of the law, an opportunity such as never before existed to claim and receive the position which rightfully belongs to him.

There arises now and then among our engineers a man with this quality of looking into the future—call it genius, call it insight, call it imagination. One of your own members said in a memorable speech that the thing which distinguishes a man of the first rank in his profession from a man of the second rank is the possession of this quality of imagination. Unfortunately it is rare. We cannot all of us have it. But we can have more of it than we now have, if we will modify our training and widen our standards of professional success. Excellent as is the course in our technical schools, it does tend to have a narrowing effect instead of a broadening one. The ideals of our engineering societies are high, but they are not always as broad as they might be. The widening of the course in the schools and greater readiness in our associations to recognize services which we now call non-professional, will, I am convinced, do more for the engineers and more for the community than would be represented by ten years' progress in mining or machinery and the various developments of applied science.

We celebrate to-day, and we are justified in celebrating, the recognition of science as a necessary guide in the conduct of the material affairs of each man's business. Half a century hence, when our descendants shall meet in this building or some yet greater building, I am confident that they will celebrate a yet greater thing—the recognition of the right of men of science to take the lead in enlightening the thought of the people on public affairs, and the responsibilty of filling the highest positions in the service of the commonwealth.

[Music. Hallelujah Chorus. Handel.]

Formal Dedication of the Building

Charles Wallace Hunt: The dedicatory ceremonies appointed for the day having been completed, I declare that this building is duly dedicated to the advancement of the engineering arts and sciences in all their branches

EVENING RECEPTION

9.00 p.m.—10.30 p.m. General reception in the main auditorium.

10.00 p.m. Reception by the officers and councils of the founder societies in their respective headquarters. The American Institute of Mining Engineers, ninth floor. The American Institute of Electrical Engineers, tenth floor; The American Society of Mechanical Engineers, eleventh floor.

Refreshments were served during the evening on the fifth floor.

Music in main auditorium, and on fifth, and library floors.

Wednesday, April 17, 1907, at 3 p.m.

John W. Lieb, Jr.: In opening the dedicatory exercises on Wednesday, April 17, 1907, at 3 p.m., John W. Lieb, Jr., chairman of the dedication committee, said in part:

In the dedicatory exercises of yesterday we gave expression to the deep gratitude of the engineering profession to Andrew Carnegie for his splendid gift; and our honored guests, distinguished visitors, and fellow society members, have enjoyed the opportunity of inspecting the building and its equipment and of observing how completely the architect and the building committee, in harmonious coöperation, have succeeded in the difficult task of meeting the unusual requirements and for which there existed no precedent.

The simple language in which the gift was conveyed: "It will give me great pleasure to devote, say, one and a-half million dollars to erect a Union Building for you all, in New York City", and which will be preserved on the bronze memorial tablet opposite the entrance, was quite unique in the history of similar great benefactions. And while it reflects the broad and liberal spirit of the donor, it also placed upon the recipients the full responsibility of building wisely and administering efficiently.

We meet to-day under the auspices of the founder societies; the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, and the American Institute of Mining Engineers, to receive felicitations from our friends abroad and at home, and for the interchange of congratulations among the members of the founder societies and associate societies on the successful completion of this building.

And as we meet to-day on founders' day, it may not be inappropriate, having given Mr. Carnegie full meed for his munificence and liberality, also to say a word as to the members and friends of the founder societies. The founder societies, in order to reach the condition which has enabled them to take upon themselves the responsibility of erecting this great building, have borne the additional responsibility of providing the land on which the building now stands. Liberal gifts from the members and friends of these societies have made this possible. The several societies have been the recipients of magnificent gifts, in many cases of complete and valuable libraries. These libraries form to-day a collection of engineering literature which will undoubtedly ultimately result in the greatest engineering and scientific library in the world.

A word should also be said of the work done by the members of the conference and building committees. To name all of the members, and to award to each the degree of praise to which he is entitled, would be a difficult task; suffice it to say that every member of these committees has coöperated cheerfully towards framing the agreements which were necessary in order properly to administer the financial affairs of this building and the land on which it stands. Perfect harmony has ruled in all our numerous conferences.

On behalf of the founder societies, I beg leave to extend to the distinguished representatives of sister societies and of the institutions of learning who honor the occasion with their presence our most hearty thanks for the interest they show by taking part in our dedicatory exercises, and we bid them thrice welcome.

It is with particular pleasure that we extend our warmest greetings to the eminent representatives of sister societies from abroad; to them we extend the hand of professional fellowship, and we ask them to share with us in the joys of these festivities.

Engineers have ever been leaders in promoting international friendships, and by their international congresses and the interchange of visits between foreign societies they have established the most enduring cordiality of relations between large bodies of influential men, separated it is true by national boundaries, but having common professional ideals and the same spirit of enlightened progress. We may, in fact, at this time rightly consider ourselves a kind of auxiliary to the great International Peace Congress which is now meeting in this city. The engineering societies are now enjoying, through the generosity of Mr. Carnegie and the coöperation of the freinds and members of the societies, the realization of the fond hopes which they have cherished for years. With the opening of this building there opens also a new era for the engineering profession in this country.

The magnificent facilities which the societies have now at their disposal should go far toward making coöperation among the various branches of the engineering profession more effective, securing to the engineer that high standing in the community to which his accomplishments, both literal and constructive, justly entitle him.

We also welcome the representatives of the associate societies who with us enjoy these opportunities, who coöperate with us in the industrial applications of engineering science, and also share our triumphs.

We hope that to our guests and friends, as well as to the membership of our engineering societies, these spacious halls and pleasant meeting rooms will be a new source of inspiration, awakening a greater pride in the profession we have chosen, and dedicating ourselves anew to the pursuit of the highest professional ideals, to the increase of human knowledge, and to the advancement of civilization.

Address by Samuel Sheldon

PRESIDENT OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Even a casual visitor to the edifice whose dedication is the occasion of the present festivities, must be impressed by its simplicity, its beauty, and its substantiality. The personnel of the executive departments of the associated Societies that have here domiciled themselves recognize its fitness and its spaciousness. All these qualities will endure except the last. The future will doubtless bring a congestion of occupancy which seems to be an inevitable metropolitan characteristic.

The Founder Societies at the present time have a total membership of nearly 12,000. Of these members more than 15% live in New York City or in its vicinity, and to them the building is accessible. Eight Associate Societies who are also at home here have a membership of approximately 4,000, about 40% of whom dwell in this vicinity. An inspection of the curves of growth of membership in the three Founder Societies shows that the present enrolment will be doubled in 1920, if past policies of management be maintained. Even times of financial depression do not lessen the membership but lessen its rate of growth. But the short period of joint occupancy just elapsed, has evidenced a stimulation to increased activity which if maintained will make membership more desirable, and a greater increment may be expected.

During the last few years there has been a rapid growth in civilization: commerce, traffic, manufactures, organization, fortunes, knowledge, and individual efficiencies have increased. Excessive and extraordinary growth has resulted from the efforts of Electrical Engineers. Doubtless this is due to the youthfulness of the profession, whose oldest workers are not thinking of retirement but on the contrary are enthusiastically and energetically productive.

Rapid growth and the character of his work necessitates that the Engineer shall continually deal with the probabilities of the future. The remarkable economies resulting from an extensive engineering study based upon more or less uncertain future conditions of the problem of supplying telephone service in New York City twenty years hence, were called to the attention of the members of the American Institue of Electrical Engineers in a recent paper. We are all familiar with the frantic struggles of engineers in charge of public utility central stations in their efforts to have modern apparatus manufactured, purchased, and installed quick enough to carry the ever-increasing load, but not so quick as long to stand idle and bring down the wrath of the financier. Reprehensible neglect to consider future conditions has resulted in an intolerable congestion of traffic in certain parts of this city. One cannot but admire the circumspection of the engineer who designed the bridges of the Western Railroad in Massachusetts, so as to carry two tracks, although the practicability of the steam locomotive had not as yet been demonstrated and a double-track road had not been seriously contemplated. One cannot but regret that the engineer, who let his rule slip when he established the standard track gauge at 4 ft. 8-½ in. had not the circumspection to let it slip in the other direction, that thereby might have been a present amelioration of the troubles of the Great. But all must congratulate those who engineered the construction of this building that they, like the Prophets of Biblical times, like all good generals in times of war, and like all good statesmen in times of peace, looked into the future in designing this, our home.

The Constitution of the American Institue of Electrical Engineers states that "Its objects shall be the advancement of the theory and practice of Electrical Engineering and of the Arts and Sciences connected with the production and utilization of electricity."

The results of recent scientific investigation show that it does not lie within the power of man to produce electricity, and accumulated experience preempts to the electrical engineer the transformation of other forms of energy into electrical energy, its transmission and its adaptation for purposes of utilization. To the efficient, flexible, and convenient manner in which these things can be done is due the development of the art. The accomplishment of this work has brought about a natural classification of the workers into: first, those who design, manufacture, and adapt apparatus; secondly, those who purchase, erect, and install it; and, thirdly, those who operate and maintain it. Economic evolution has placed the manufacture in the hands of a few large corporations that require for their work the coöperation of all types of human endeavor. In their employ are to be found, besides those found in every other industrial organization, engineers of all kinds, even military and naval.

Because of the great magnitude of modern engineering undertakings and the desire for high efficiency there is a marked tendency to entrust the purchase, erection, and installation of electrical apparatus to large engineering organizations. Such a one in the West, whose head is a prominent electrical engineer, includes in its staff one or more electrical, civil, mechanical, structural, sanitary, chemical, gas, hydraulic, mining, industrial, and operating engineers. The natural results of the existence of such an organized staff is the undertaking of other than electrical installations. A firm in New York City, besides installing electric railways, power and lighting plants, is engaged in the constructing of sewerage systems, and in the erecting of banks, theatres, hotels, terminal stations, and other large structures. To such an organization the financing and engineering construction of the Panama Canal would be a natural and a feasible undertaking.

To those engineers who are engaged in the operation of electrical plants generally falls the task of purchase, erection, and installation of additional equipment necessitated by growth. Upon their staffs are also to be found various types of engineers.

These instances merely illustrate the condition of man's limitations because of his environment, and emphasize that the social fabric rests upon the interdependence of individuals and the redemptive economy that results from correlation of individual efforts. Try as we may to limit the spheres of our activities and to direct the lines of our intellectual growth, the potentiality of its seeds is beyond our control; and fortunate are we that there now portends an appropriate nourishment in the intercourse between the cohabitants of our new home.

Some Significances of the Engineers' Building, by Frederick R. Hutton

PRESIDENT OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

I. WHO IS A REPRESENTATIVE MECHANICAL ENGINEER.

He who would fain speak in any adequate way as a representative of the profession of mechanical engineering and of its practitioners in the American society must recognize that the field of his outlook is exceedingly broad.

The electrical engineer has made his own the field of transmission of energy for light and power, and for transportation by railway, and for communication between individuals.

The mining engineer and metallurgist have conquered the winning of buried wealth from the earth and the process of making it available for industry, and the production of wealth.

The function of the mechanical engineer has, therefore, been to share with the civil engineer the industrial activities in the rest of the field of practical achievement.

If to the latter be assigned the permanent way of the railroad and the highway and their bridges, the canal, the municipal field in water-works and draining and the designing of the braced structure as his specialties, there remains to the mechanical engineer the duty of generating or liberating power for all sorts and conditions of engineer, and the duty of design and creation of apparatus for the broad field of manufacturing. It would appear, therefore, that he will be most generally representative of mechanical engineering, who places himself in the area devoted to the generation of power, which underlies all production on a large scale. He is also the one who creates machinery and tools for manufacturing and production in all lines, and who concerns himself with the operation of such plants and the consequent creation of wealth. I believe that the mechanical engineer of the twentieth century is to be the manufacturing engineer.

II. THE INTERNAL SIGNIFICANCE OF THE BUILDING TO ENGINEERS.

If the foregoing be conceded then the dedication of the Engineers' Building at this time emphasizes the noteworthy economic significance of such a building. It has become, therefore, the gift of a great producer to the great factors of production.

The owner of a mine is not enriched until by the expenditure of skill, power and labor, the buried ore has been won and made available. The crude ore at the surface is not of full value until the engineer of transportation by land or water has brought it to the door of the metallurgical engineer, who, by expending skill, power, and labor upon it, changes it to useful metal. The metal is not of market value until the mechanical engineer by skill, power, machinery, and labor, has brought the metal to its merchant forms in which it can be sold and used.

In the next stage and after the purely productive process over which engineers have presided, will come the industrial or commercial application of the materials. For these again, it is the engineer who has created the need. The railway rail, the beam, the plate, the bar, the casting and the forging are all made and sold to meet the call of the designer, the builder, and the user of the constructive elements in modern production. For all the wealth represented in plant and product, it is an engineer who has signed the call. It is his rubbing of the Aladdin lamp of knowledge and skill, which has brought into existence the material result. It is a tribute to the insight and ideals of the donor of the building that he should have seen that by helping to foster the engineer himself, he has raised a most notable monument to economic betterment and the uplift of the community. The building, supplying facilities for engineers' meetings, for an engineers' library, and for the executive work of engineering organizations, has helped to raise and to advance the already exalted standard of that profession within its own bounds.

III. The External Significance of the Building.

But the Engineers' Building has not alone a meaning and significance to those who are to be within it and who benefit so directly by its provisions for comfort and for progress. It has an external significance and a meaning to those who are without. It stands in dignity and majesty as a public building on an eminence to deliver to luxury and thoughtlessness its uplifting message. It stands to teach that wealth or mere accumulation does not create or perpetuate itself until it is used. All consequent possibility of culture, education, refinement, and art are latent in wealth, but lie hidden there until it is devoted to industrial production. Mere manipulation of securities or purely capitalistic financing does not produce wealth. In manipulation, wealth may change owners, but one is poorer because the other is richer. The Engineers' Building stands for the real creation of community wealth where a real asset of value is made to enrich both owner and community by multiplying itself in accordance with physical and economic law. No production of wealth is real or can continue which is in defiance of law or fact. The engineers for whom this building exists are students and practitioners of their craft and avocation in conformity with such law. Knowledge of such necessary laws lies at the base of the prosperity which the community enjoys.

IV. Educational Significance of the Building.

This makes the Engineers' Building at once a beacon and a plea for engineering education. This must be such training as shall fit the engineer to conduct continuous and successful production in accordance with the requirements of physical and economic law. The scientist and the laboratory worker and the man of affairs must be expected to discover, formulate, and apply these laws. The building is, therefore, a monument to what the engineering school and the scientist have done and are yet to do for the advancement of our civilization in educating its engineers.

V. Economic Significance of the Building.

Finally, the Engineers' Building stands to rebuke certain economic fallacies. It is a convincing answer to a contention that physical toil and manual labor of arm and brawn are the only real creators of wealth in the production process, and that the reward of toil is to be directed entirely to him who contributes bodily effort. It says to such a theorist that misdirected toil and labor, which goes for naught through ignorance of physical or economic law, will impoverish the community, not enrich it. Experiments are costly when at their basis lie assumptions contrary to fact and truth. Furthermore, labor must be organized and must be directed by knowledge: its tools and its operations must also be designed and planned on a basis of knowledge and experiment. The director and organizer of labor is, therefore, to be compensated both practically and in public consideration in proportion to his economic value. The engineer as a factor in production far transcends the significance of the mere craftsman, and this building evidences the truth and the fact. The economic future does not lie amid the dreariness of some of the contentions of the socialist, It lies in releasing more and more the human unit from the stress which we lay upon the beast of burden. In this releasing process the engineers will be inevitably the leaders.

VI. CONCLUSIONS.

In conclusion, therefore, I ask you to agree with me in these contentions three:

I. That this building is a gift to favor production as a factor in creating wealth, itself an antecedent to progress in art, civilization, culture, and literature.

II. That it should stand in its city as a monument for sound thinking on the position of the engineer and his relation to wealth and its production by knowledge and by skill working in accordance with natural law; and, therefore, for the significance of engineering education as favoring such sound thought.

III. That as a consequence of these the community as a whole as well as the organizations directly benefited by the building owe a debt of obligation and recognition to him who has made all this possible.

Address by John Hays Hammond

PRESIDENT OF THE AMERICAN INSTITUTE OF MINING ENGINEERS

This is unquestionably the era of the engineer the world over, and especially is this true in respect of America. To the skill of her engineers in the exploitation of her unparalleled resources America owes her recognized preeminence in the industrial world. In the development of new fields for industry, the engineers has played a conspicuous part. First, comes the mining engineer, the pioneer of civilization, penetrating the dense jungles of the tropics and traversing the over-frozen North in the quest for gold. His indomitable pluck, his indefatigable energy and his professional skill have sometimes resulted in the discovery of a new territory for human activity and have sometimes, alas! availed naught to save the adding of his name to the already long list of victims of disease or of murderous savages.

Closely following the adventurous mining engineer have come in turn, the civil, the mechanical, and the electrical engineers to contribute their labors to the sum of achievement in the advancement of civilization. While the mining engineer has been the pioneer, he recognizes the indispensable coöperation of his confreres and the fraternal congratulation of their common success in this intellectual teamwork, through which lost motion is prevented and the highest results are obtained. He rejoices with them in the wise provision of the generous donor of this, our Engineers' Building.

This building becomes a clearing house of engineering information, facilitating as it does, interchange of professional knowledge through the trinity library and through the personal intercourse of engineers of several specialities. If we avail ourselves, as we undoubtedly shall, of the opportuntities thus afforded to us, we shall contribute in a large measure to the renown of our profession, to the benefit of mankind in general, and to the acknowledgment of our debt to our benefactor, Andrew Carnegie.

JOHN W. LIEB, JR.: The gift by Mr. Carnegie was made to the three founder societies, and to the Engineers' Club, which thereby becomes our co-partner in the joint enterprise. It is therefore proper that we should call upon our partner, bound to us by ties of friendship and of neighborliness. We have let them in on the ground floor, and by a still higher tie connecting the two buildings at the ninth story. I am glad to call upon Mr. T. Commerford Martin, President of the Engineers' Club.

Greetings from the Engineers' Club

BY T. COMMERFORD MARTIN.

To our fellow engineers, who've been looking many years,
Uptown and down, for a home whose rental wasn't high;
We, members of the Club, which has also felt that rub,
Bring greetings from our Little House nearby.

With you we share the gift; with yours, our voices lift
In praises of Carnegie, who aimed our kindred fate to tie.
" A home for you all " is graven on your wall,
And, deeper, on the cozy Little Club nearby.

Here may brethren dwell in peace; here may your tribes increase;
Here may the founts of knowledge ne'er run dry.
But for leisure moments sunny, or refreshing milk and honey,
Come over to the kindly Little House nearby.

When weary of the jargon of 4π and of argon,
And of engineering problems that daily multiply;
Just step across the alley, or by the high bridge sally,
To the solace of the cheery Little Club nearby.

You are mining or electrical, railway or mechanical,
All for truth and fact and data in full cry;
But in the Club we're human—not forgetting there is woman—
And *all* are welcome in the Little House nearby.

To us within these walls, to all fair science calls.
Onward and upward as our temples pierce the sky!
So to your flow of soul, we shall pledge a brimming bowl,
Comrades! playmates! in the Little Club nearby.

JOHN W. LIEB, JR.: It has always been one of the features of the social life connected with our professional engineering bodies that they have fraternized, not only among themselves, that they have spread their hands across the sea to their brothers in foreign lands. We have had numerous interchanges of visits, and it is always a welcome occasion that brings anew the opportunity of seeing our friends from abroad.

Among the distinguished guests that we have with us to-day is an old friend of many of the members of the engineering societies, and I shall call upon the special representative of the Institution of Electrical Engineers of Great Britain, Sir William Henry Preece.

Address by Sir William Henry Preece, K.C.B., F.R.S.

It is an old Latin proverb which says, *Poeta nascitur, non fit*, which roughly translated is, poets are born and not made.

We have had before us just now an unknown poet, and I must say I think we shall all agree that he must have been born so, for the natural tendency in the matter-of-fact business that he is engaged in is not one that would aid him in pouring forth such a beautiful welcome in such charming words.

I am here as an engineer who believes in facts. I was not born a poet, and it is my duty as the representative of the British Institution of Electrical Engineers to express for them the great pleasure we have in supporting the new movement that has taken place here, or rather in taking part in the exercises which are culminated in this meeting to-day.

I think that my friends at home must have been afraid of my being tempted elsewhere during this week, for they have sent me a message to remind me of what my duty ought to be. I received this morning a message which says:

"The president and council of the Institution of Electrical Engineers send most cordial greetings to the sister institute on the occasion of the dedication of their new home."

I would say, speaking as a member of the Institution, that it gives me the geatest pleasure to be here; and I can say more on my own behalf, that I appear here not only as the representative of the English institution of Electrical Engineers, but also, as you will see by this badge, as an Honorary Member of the American Institute of Electrical Engineers. In fact, I hold a unique position. It is a kind of a duplex position, for there are only two honorary members—one is Lord Kelvin, and the other is W. H. Preece. And I was about to say that there is no honor that I hold higher than the position of Honorary Member of your Institute.

I felt strongly inclined, when Professor Hutton referred to the functions of the engineering societies, to tell him that if one wants to know a little something of the history of the mechanical engineer he should study his Bible, for there he will find in one of the earlier chapters of Genesis that, according to the King James version, "Tubal-cain was an instructor of every artificer in brass and iron."* So then we learn, that in very early days there was something like technical education. That version has been revised in the new edition, and it says: "Tubal-cain was a forger of every cutting instrument of brass and iron." I hope that Mr. Hatfield, who represents the great industry of cutting tools in Sheffield, will take back home with him this fact that I have found for him, if he did not know it before, in a very old book which I am glad to say many of us read as often as we possibly can.

Sir, I do not know the time that you are going to allot to your speakers, but I can say this, that anybody here who is anxious to hear me on these points—I am such a crank in speaking about what engineering has done, and what engineering is that I can go on as long as to-morrow morning. Eschewing engineering subjects for the moment, I wish to say that it is with earnest feelings of pleasure and delight that I come to take part in the proceedings of your Institute. Nothing gives me so much pleasure as to come across the Atlantic, for I find that I can go back home with energy renewed, charged with energy such as we do not know at home until we have been over here. I am impressed always with the advances made, and I am glad to think I have had the opportunity and I hope I shall have it again, to impress upon my fellow-countrymen the advantages of coming across the ocean to see you.

Brief congratulatory remarks were then made as follows:

On behalf of the American universities, by Mr. Walter C. Kerr, trustee of The Cornell University.

On behalf of the Iron and Steel Institute of Great Britain, by Mr. R.A. Hatfield. Mr. Hatfield presented the United Engineering Society with an illuminated manuscript from the Iron and Steel Institute, the Institution of Civil Engineers, and the Institution of Mechanical Engineers of Great Britain.

On behalf of the Freibund Deutscher Elecktrische Technic, by Dr. Frederick Eichler.

On behalf of the American Society of Civil Engineers, past-president John Findlay Wallace read the following letter from president G. H. Benzenberg:

"Though not a member of either of your societies, I would like to have joined with you in giving hearty expression and acknowledgment of the splendid and generous recognition which Mr. Carnegie has given to American engineers by this magnificent gift. This recognition of the achievements of the profession should stimulate and inspire every one of us to a higher accomplishment and to nobler purposes, so that the lofty motive which actuated the donor when he formulated his proposal may have its warrant in the further progress made by the engineer in every branch of his profession, between which no envy or rivalry should ever exist, excepting that contention of the engineering profession in every branch for the benefit of the profession at large.

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*Genesis IV, 22.

May this home be a monument to the eminence and standing which the engineer has attained in every branch of the great industrial advancement of this country, and may his further progress and success in the economical development of the resources of nature for the use and benefit of man bring to him the full recognition he shall deserve.

Please accept and convey my sincerest good wishes and congratulations to the societies upon this occasion of the memorable opening of their new home, and may the spirit of peace, progress, and prosperity ever dwell within its walls."

Address of Dr. Henry Pritchett

PRESIDENT OF THE CARNEGIE FOUNDATION.

We who labor in the preparation of men for the calling of the engineer feel a keen interest in your success and in your gift, and, for two reasons; first, because we have seen here an effort towards coöperation and unity, and we feel that progress is in accord with the spirit of the age. There could be no more fitting time to dedicate such a building as this, occupied and to be held by the engineering societies, than at the time of the meeting of a great peace conference. Secondly, we feel a great interest in this evidence of prosperity on the part of your societies, because it is a recognition of the dignity and of the value of the calling of the engineer.

After all, the engineer is the real civilizer of to-day, is the real advance agent of civilization and of culture. I cannot but think that such a building engineering could have been given no more fittingly by any one than by a man born in Scotland, because Scotland was civilized by engineers. There is a tradition that it was done by the poet and by the priest and by the university, but as a matter of fact it was done by the engineer.

The story is a short one. At the end of the eighteenth century the inhabitants of Scotland were still engaged in the noble business of lifting cattle from their southern neighbors. I have no doubt that the Carnegie clan got its full share. They had poets, they had prophets, they had universities, but they lacked civilization. Four engineers came along and civilized them. One taught them how to build roads, and his name is perpetuated to-day in the street pavement known as the Telford. The second taught them how to build a bridge across a stream. A third, and perhaps he was the greatest of all, taught them how to harness the power of steam. The fourth taught them how to draw a wagon on two rails with steam power. Those four men did in fifty years more than all the poets and prophets and universities had not done in a thousand years; they changed the country from a generation of cattle lifters to a generation of civilized men.

Speaking in all seriousness, sir, this building is of greatest moment to us because it does recognize that very fact. Your engineer is to-day the real worker in civilization. He is not a poet, he is not a prophet, he is not a priest; but he is a constructor. He represents the constructive side of human development, not the destructive side or the passive side, and as such he is the real maker of the civilization of our day.

What is it that makes civilization? What is it that civilized Scotland? It was the making of transportation, it was the bringing of men together; for it is not weakness that brings war and that makes peace impossible, but it is the ignorance, the lack of knowledge of one people of another, that makes war possible and that brings with it all the horrors which war entails. He who builds the railroad, he who throws a bridge across a stream, he who makes transportation possible,—they are the men who build the enduring paths of peace and of civilization.

So we, sir, of the .technical school, ask you as engineers that you may help us in our work of instruction to realize, and to make our students realize, that the engineer is the builder not only of material civilization, but that he must be in this next quarter century a builder also of those structures which look towards things which are spiritual and towards things which are eternal.

On behalf of the Verein Deutscher Gesellschaft, Mr. Charles Kirchhoff said:

I come to you to-day to bring the greetings of one of our German sister societies, whose headquarters are in that beautiful city on the Rhine, Dusseldorff, where they have cunningly succeeded in establishing both an art centre and an industrial centre. The foreign societies and the societies on this side of the water have repeatedly exchanged visits. I have been a guest on some of these occasions; I can assure you that if I should be a host in future years you will find true again what you have found in the past: there is an open hand, an open heart, and an open cellar door ready for you at all times.

Mr. Kirchhoff then presented the United Engineering Societies with an illuminated manuscript from the Verein Deutscher Gesellschaft.

On behalf of the Societe Internationale des Electricite of France, by Mr. Carl Hering.

On behalf of the Faraday Society of Great Britain, by Mr. Leon Gasper.

On behalf of the Canadian Society of Civil Engineers, a congratulatory telegram from the president, Mr. W. Michael Wellbank.

On behalf of the Associazione Elettrotechia Italiana, and the Italian Society of Engineers and Architects, by Mr. John W. Lieb, Jr.

On behalf of the Berlin Observatory, by Dr. F. R. Archenhold.

On behalf of the associate societies in the Engineers' Building, by Captain Baxter, United States Navy.

Mr. Lieb then read a large number of congratulatory letters and telegrams from all parts of the world. Among these were the following:

London, April 4, 1907.

" I am sorry it is not possible for me to present on the occasion of the dedication of the building of the Engineering Societies on April 16 and 17, as I must be in London at that time.

Kelvin."

" Institution of Civil Engineers, Great Britain. Under a resolution of the council I have the honor to request you to convey to the trustees of the United Engineering Societies the very warm congratulations of this Institution upon the occasion of the dedication of the new building established as a home for American engineering societies. With an expression of the hope that it may be the means of furthering the interest of the engineering profession and of establishing more closely the relations which exist between its various branches I have the honor to be, sir, your obedient servant,

" J. H. T. Bacborough, Secretary."

" Council of Institution of Mining and Metallurgy now assembled send cordial congratulations to American confreres on dedication of the United Engineering building."

John W. Lieb, Jr.: We have to-day as one of the features of our programme the presentation of the John Fritz gold medal, and as an introduction to the presentation of that medal I will ask Mr. Fritz kindly to be seated on the platform. [Mr. Fritz took the platform amid great applause.] This medal, as you may know, was founded by a number of friends—and he has a host of them in the engineering profession—of our honored colleague, John Fritz.

The American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, and the American Institute of Electrical Engineers, constitute a board through their representatives which awards this medal Mr. Charles F. Scott is the chairman of the board which has awarded the medal. this year to Dr. Alexander Graham Bell.

John Fritz Medal.

Presentation of medal by Charles. F. Scott, chairman of the Board of Award, April 17, 1907:

The presentation of the John Fritz medal on this occasion has a peculiar significance, for this noble building owes much to the John Fritz medal. The happy outcome of the coöperative movement by which the national engineering societies joined in the founding of this medal, and the brilliant dinner to John Fritz on October 31, 1902, did much to develop the sentiment of which this building is the outcome. Mr. Fritz, in grateful response to the honor he had received, was the nestor of the committee to whom Mr. Carnegie handed his letter of gift. I am personally glad to acknowledge that it is to the John Fritz dinner that I owe an acquaintance with the several societies, and a conception of what engineering societies may accomplish when they work together. The ideals which were there inspired have been the impelling force in my relations to the noble enterprise which is consummated in the dedication of this building.

The vision of the future which seemed to show a reflection of the John Fritz medal in a larger life of the engineer of the twentieth century, was discerned by the keen eye of a genius in foreseeing and in inaugurating movements for the upbuilding of men, and by a touch of his magic wand of wealth he has brought it to a reality in this magnificent building—the capitol of American engineering.

This medal signifies more than a bit of gold, more than honor to a man for his achievements. It stands for a sentiment, for a new ideal from which many results may follow. As one of the first fruits to which it has contributed has come this noble building.

On this dedicatory occasion the first formal announcement is made of the awards of the John Fritz medal. The first award was made on January 20, 1905, to Lord Kelvin, "For his work in cable-telegraphy, and other scientific achievements." The second award was made on January 19, 1906, to George Westinghouse, "For the invention and development of the air brake." The third award was made on January 18, 1907, to Alexander Graham Bell.

Dr. Bell, on behalf of the Board of Award of the John Fritz medal, consisting of Messrs. Charles Warren Hunt, Charles Hermany, C. C. Schneider, and Frederic P. Stearns, from the American Society of Civil Engineers; of Messrs. Charles Kirchhoff, E. E. Olcott, E. G. Spilsbury, and James Douglas, from the American Institute of Mining Engineers; of Messrs. S. T. Wellman, James M. Dodge, John E. Sweet, and Henry R. Towne, from the American Society of Mechanical Engineers; and of Messrs. Charles F. Scott, B. J. Arnold, J. W. Lieb, Jr., and Schuyler S. Wheeler, from the American Institute of Electrical Engineers, I have the honor to present to you this medal, for the invention and introduction of the telephone.

RESPONSE OF ALEXANDER GRAHAM BELL.

I hardly know how to express myself fittingly in response to the honor that is bestowed upon me. I can only say that I appreciate very highly this medal, and I shall prize it also from the fact of its being presented in this magnificent building, this temple dedicated to applied sciences, the home of the societies of engineers; but I think that what will give this medal even greater impress in my recollection will be the fact that it is presented in the presence of the venerable John Fritz himself.

JOHN W. LIEB, JR.: As has already been stated to-day, the engineering societies have for many years labored under extraordinary difficulties in unsatisfactory and inadequate quarters. That the engineering societies under such disadvantages did individually thrive and grow is nothing short of marvelous, but we have had in the meantime the work of the indefatigable secretary. In undertaking to choose whom I should first present in connection with the presentation of the medal which is hereafter to be entitled " Distinguished Service Medal," to which of these gentlemen we should first call to the platform, my first inquiry was as to their relative length of service, and when I say to you that two of them had 23 years' service, one 22 years, I do not think we can make any distinction on that account. I therefore call upon Dr. A. R. Ledoux, past-president of the American Institute of Mining Engineers, representing the three societies, to present these medals.

Address by Dr. Albert R. Ledoux.

There is a saying that republics are ungrateful. The same is sometimes affirmed of "soulless corporations." But this cannot be charged against our three societies; for the dominant note of these exercises has been gratitude for this splendid home in which we will dwell together in fraternal unity, but there are still other notes of gratitude that we would sound to-day.

In every organization, whether the individual units are represented by trustees, or directors, or committees, there is always some one man who does the greater part of the work. With us, it is the secretary. Presidents come and go, but the secretary works on unceasingly. We have been most fortunate in our three secretaries, not only on account of their remarkable executive ability, not only on account of their tactfulness and other qualifications of mind and heart, but on account of their unselfish willingness to devote so many of the best years of their lives to our several interests. During their official incumbency, we have developed from small beginnings to the splendid aggregregation of nearly 12,000 members. Whatever may be the achievements of their successors in office, these men have set a standard which it will be difficult for anyone to surpass.

Ralph Wainwright Pope

The American Institute of Electrical Engineers was organized in 1884. In 1885, Ralph Wainwright Pope was elected its secretary. Born August 16, 1844, educated at Great Barrington and Amherst academies, he developed early in his career a marked taste for mechanics, and has been continuously identified with what might be called applied electricity. He entered the service of the Housatonic Railroad in 1859. At the outbreak of the Civil War, he entered the service of the American Telegraph Company and became an expert telegrapher. Later he joined the famous Collins Overland Telegraph Expedition, which the success of the Atlantic cable prevented from establishing connection with Europe across the wilds of British Columbia, Alaska, and Siberia. Mr. Pope was for ten years subsequently in the service of the Gold and Stock Telegraph Company, resigning the position of deputy superintendent in 1883. From that date until 1888, he was actively engaged in the editing and publishing of technical electrical papers in this city.

But it is of his service as secretary that I speak with especial emphasis. During his tactful administration, the growth of the Institute has been rapid. In 1887, he consented to devote practically all of his time to its interests alone. He has made a constant study of its needs and has not hesitated to recommend the adoption of all that appealed to him as desirable in the methods and activities of other technical organizations. Perhaps the best evidence of the appreciation of Mr. Pope's service is that furnished by the members of the Institute itself. The office of secretary is purely elective, and the term is only one year. Mr. Pope has been re-elected twenty-two times without opposition.

His clear conception of details; his genius for taking pains; and the orderly methods of his office, have earned for him the affection and the gratitude of the directors and members of the American Institute of Electrical Engineers, whose wishes he has so ably carried out.

Frederick Remsen Hutton

Long may it be said of our secretaries that none die! But it can no longer be said that none ever resigns, for the record of the trio, whom to-day we honor, has just been broken by the election (I do not say promotion) of Secretary Frederick Remsen Hutton to the presidency of the American Society of Mechanical Engineers. Dr. Hutton was born in this city on May 28, 1853, was graduated from Columbia University in 1873 as A.B., received the degrees of M.E. in 1876, Ph.D. in 1882,and Sc.D. in 1904. Since his graduation and up to the present time, Dr. Hutton has been intimately connected with the life and growth of his alma mater. He was, as instructor in mechanical engineering, associated with the late Professor W. P. Trowbridge; was appointed adjunct professor in 1881, and full professor in 1890, and was dean of the faculty of applied science for many years.

Perhaps Professor Hutton has left his most enduring mark upon Columbia University, through his successful efforts to create and equip one of the most complete mechanical laboratories possessed by any of our technical schools. He has found time in the midst of many exciting duties, not only to devote his abilities to the building up of the American Society of Mechanical Engineers, but to many outside activities. He has been school trustee, editor of the Engineering Magazine; one of the editors of Johnson's Encyclopedia, the Century Dictionary, the author of works on mechanical engineering, power plants, heat engines, machine tools, the gas engine. Like Mr. Pope, President Hutton has rounded out almost a quarter of a century in the office of secretary of his society, for he was elected to that office in 1883, and annually ever since until he declined a re-election in 1907.

Members of this society are unanimous in the statement that its growth has been largely due to the energy and optimism of its secretary. Through his initiative many valuable additions to its library were acquired. It was his courage that made it possible to purchase the headquarters building in West Thirty-first Street, the recent sale of which at double the cost price confirms the wisdom of the venture.

During the last three years, a double burden has been placed upon the shoulders of Dr. Hutton, for he has also been the secretary and one of the most active members of that unique body of allied engineers, known as the trustees of United Engineering Society, and of the building committee, charged with the design, erection, and maintenance of the edifice in which we assembled today. Would that I had the gift of language of Dr. Hutton, that I might in adequate terms express appreciation of the symmetry and order which he has injected into the proceedings and records of all of these organizations, and in this, I can speak with knowledge, for until 1906, I had the honor to be a member of the United Engineering Society.

Rossiter Worthington Raymond

I turn now to mention another of our three great secretaries, Rossiter Worthington Raymond. I have found it difficult, for personal reasons, to confine myself to an enumeration of the public services of this veteran officer of the American Institute of Mining Engineers, for my association with him has been very intimate. We have counselled together for the Institute, in dark days and in bright, and, for nearly a decade occupants of the same building, we came in daily, personal contact. But I must forbear to say what I would of his lovable qualities as a man. Dr. Raymond was born in Cincinnati on April 27, 1840. After education in public and high schools, he was graduated from the Polytechnic Institute of Brooklyn, in 1858, at the head of his class. He was one of the first of our great American mining engineers to take advantage of the instruction at the mining academy at Freiburg, Saxony, after courses at the universities at Heidelberg and Münich.

Returning to America in 1861, he enlisted in the Union army, and resigned in 1864 with the rank of captain. He was on the staff of Major-general Fremont during the campaign in the valley of Virginia. From 1864, Dr. Raymond has practised as a consulting mining engineer and metallurgist. In 1867, he became the editor of the American Journal of Mining, the predecessor of the Engineering and Mining Journal, in the establishment of which he had a large share, the weight of his pen being one of the contributing factors of its continued success. In 1868, he was appointed United States Commissioner of Mining Statistics, which position he retained until 1876, editing eight monumental reports. He was lecturer on economic geology at Lafayette College, from which he received the honorary degree of Doctor of Philosophy in 1870. From Lehigh University he received the degree of LL.D. in 1906.

The American Institute of Mining Engineers was established in 1871. Dr. Raymond was chosen vice-president, really discharging the active duties of the president, owing to the physical incapacity of the president, the veteran David Thomas. Dr. Raymond was thrice elected president, and was made secretary in 1884; since then he has been annually re-elected the executive of the Institute. For years he was sole editor of its Transactions. These Transactions have been the standard upon which many newer scientific bodies have modeled their publications, and upon which some of the older organizations have remodeled theirs. The products of Dr. Raymond's versatile pen have often adorned these volumes, as well as the pages of many other publications in this and in foreign countries. At the request of the United States Government, he prepared for the Geological Survey an authoritative resumé of our complex and unfortunate mining laws, upon which subject Dr. Raymond's voice has many times been heard.

Amid all his varied professional duties, Dr. Raymond has found time also to devote himself to matters outside of mining and metallurgy. In 1893, he was admitted to the bar of the Supreme Court of New York State, and subsequently to the Federal courts, and is often named in judicial decisions as an authority, particularly upon mining and patent law.

In 1885, Dr. Raymond was one of the three state Commissioners of Electrical Subways of the city of Brooklyn, and for four years its secretary. He prepared the final report, which is still quoted as one of the most important contributions to municipal engineering.

Many honorary degrees and honorary elections to important societies have been conferred upon Dr. Raymond, from all parts of the United States and from Europe. For twenty years he was the consulting engineer of the New Jersey Iron and Steel Company, the Trenton Iron Company, and other of the mining and metallurgical corporations controlled by the firm of Cooper and Hewitt.

It is surely not out of place in his presence, to mention briefly the work of Dr. Raymond along still other lines. His articles on " Labor and Law " and " Labor and Liberty," his management of the Saturday evening free popular lectures at Cooper Institute, at which he often presided, his discriminating " Life of Peter Cooper," and other writings too numerous to mention, have shown his deep grasp of our social problems and his sympathy with his brother man. His name is indissolubly associated with the work and history of Plymouth church.

In order to give public expression to the appreciation of these three founder societies for their three great secretaries, there have been prepared by the distinguished artist, Victor Brunner, three identical gold medals. Upon one side there is depicted a figure representing the spirit of invention and research, typified by a youth who holds in his hand a tablet, upon which his attention is fixed. Enveloping him is a cloud of steam, which rises from the stack of a modern locomotive, typical of mechanical engineering, above appears the top of a blast-furnace. Below and at his right hand appear the emblems of the founder societies encircled by an olive wreath, while opposite is a view of our present building, with an inscription reciting the fact and date of its dedication. Above the seated figure are suggestions of the work of the electrician and miner, represented in the one case by a high-tension electric line and in the other by men operating a power drill. Upon the obverse of each medal are inscribed the names of the recipients and the reason of its bestowal.

And now, Mr.Pope, Professor Hutton, and Dr. Raymond, I take pleasure in handing to each of you this token of our sincere appreciation and regard. In the name of our three societies I thank you for service past, and express the hope that long may you be spared to give us the benefit of your ripe experiences and the inspiration of your leadership.

Response on Behalf of the Recipients of the Medals by Frederic R. Hutton.

As the youngest in years and the longest in service, and as the man no longer in office, my colleagues have suggested that to me might fall the opportunity of a word of recognition.

On a Judean hillside on the first Christmas night three shepherds were engaged in their occupation under the open sky. They were not remarkable men. They were doing the work of the hour—the duty that lay next to them. Suddenly about them a glory of light, and a message—a message that was not to them alone, but to the whole world, that a new era had dawned. It was to be an era of good will and peace.

There have been three craftsmen sitting at their desks. They have not considered themselves remarkable men; they have been doing their daily toil; they have been doing the duty which lay next to them. Suddenly there has come to these three men a blaze of appreciation, which makes them silent and thrills them.

The message of that appreciation is not to us alone. It is to the world of engineering as well as to us and to our successors. We take it that the message and the glory mean the dawning of a new era—the new era which opens with the Engineers' Building, and is to be an era of progress, prosperity, and peace.

Professional Sessions

MONDAY, APRIL 15, 8.15 p.m.

Special meeting in main auditorium of the American Institute of Electrical Engineers, presided over by Sir W. H. Preece, K.C.B., F.R.S., past-president and representative of the Institution of Electrical Engineers of Great Britain.

Paper by Louis M. Potts on the Rowland Telegraphic System.

THURSDAY, APRIL 18, 2 p.m.

Meeting of the American Institute of Mining Engineers in main auditorium.

Illustrated paper by H. T. Hildage on Mining Engineering Operations in New York City and Vicinity

THURSDAY, APRIL 18, 8 p.m.

Meeting of the American Society of Mechanical Engineers in the main auditorium. Paper by Brig-gen. W. Crozier, U S. A., on the Ordnance Dept. as an Engineering Organization.

FRIDAY, APRIL 19, 8 p.m.

Informal smoker and vaudeville, Madison Square Garden concert hall, under the management of the American Institute of Mining Engineers for the members of the three founder societies.

Rates of Charge for Electricity and their Effect on Cost*

In considering the question of rates for the sale of electric light and power from a central station, one of the most important things to bear in mind is that only a small part of the cost of production is proportional to the output of the station. The bulk of the cost is independent of the output and consists of interest, depreciation, taxes, and insurance on real estate, generating apparatus and distributing system; the managerial, office and miscellaneous expenses, as well as the greater part of the wages, and even a small part of the coal, since frequently coal is consumed merely to keep up steam or to run engines with little or no load.

The very high proportion of fixed expenses, that is of expenses not affected by the output of the station, is a peculiarity of the electric business and is due primarily to the fact that the greater part of the demand for current is compressed into a few hours each day. This last fact is also true of the gas business, but whereas it is possible to store gas efficiently during the hours of light load, electricity must be manufactured at the moment it is called for

It follows that the capacity of the boilers and machinery, of the transformers and of the distributing mains, is determined not at all by the total output of the plant but altogether by the maximum load which the plant is called upon to carry, and therefore if this maximum load is very high in proportion to the average load on the plant, then the investment expenses of the plant will be a very large proportion of the total expenses. Now this is precisely the condition of the average station producing electricity. The maximum load is out of all proportion to the average load, or in other words, the "load-factor" of the station is very low.

The term load-factor is used a great deal by those connected with the central station business and may be perfectly familiar to all of you. Nevertheless, as I shall have occasion to use it frequently in the development of my subject, I will not take for granted that it is understood.

The load-factor is generally defined as the ratio of the average load on the station to the maximum load, and is usually expressed in percentage, thus 50% load-factor means that the average load is one-half the maximum load. The method of ascertaining the average load on the plant for a period of time is to divide the output in kilowatt-hours for the period by the number of hours in the period. For example the average load for a year is equal to the output for the year in kilowatt hours divided by 8760, the number of hours in a year.

By load-factor is sometimes meant the ratio of the average load to the capacity of the plant and the period of time referred to is not necessarily a year, so that it is important, when the term is used, to state or ascertain exactly what is meant. In this paper, however, unless otherwise stated, the term load-factor will mean the annual load-factor as above defined, and expressed algebraically, as follows:

$$\text{Load-factor} = \frac{\text{Average Load}}{\text{Maximum Load}}$$

$$= \frac{\text{Output} \div 8760}{\text{Maximum Load}}$$

$$= \frac{\text{Output}}{8760 \times \text{Maximum Load}}$$

From this last expression of load-factor it appears that another definition of it may be given as follows: that is, the ratio of the actual output of the plant to the output that it would have if it were run at maximum load for 24 hours a day, every day in the year, and further it follows that when the plant is actually run at maximum load continuously throughout the year then the load-factor is 100%.

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*A paper read by J. S. Codman, before the Boston and Cornell Branches of the American Institute of Electrical Engineers, March 20, and March 8, 1902.

This condition of running, viz., at 100% load-factor, is the ideal condition for any plant, as there is then no idle machinery except that used as reserve in case of a breakdown or to allow for growth, and what should be particularly noted is that under this condition the output being at the maximum, each kilowatt-hour of output has to carry a minimum proportion of the fixed expenses and the average cost per kilowatt-hour is therefore at a minimum.

The fact is that if electric plants generally could be run at 100% load-factor, the average price at which a kilowatt-hour could be sold would be very much less than it is at present, and a very general use of electricity for heating and cooking as well as for power and light would be an actuality instead of only a possibility as it is to-day.

Progressive central station managers to-day realize that far greater progress toward a low cost per kilowatt-hour is to be expected by improvements in load-factor than by any economies in the actual mechanical operation of a plant. Not much is to be expected now in this latter direction. The introduction of the steam turbine means a saving in space and probably also in coal consumption and in repairs to machinery, but it will not affect the average cost of a kilowatt-hour to any great extent. On the other hand there is plenty of room for improvement in load-factors. The load-factor of the average central station is very low, often less than 10% and only occasionally greater than 30%, and a slight improvement in load-factor therefore will have a great effect on the average cost per kilowatt-hour. In order to get a concrete idea of this it will be best to take an example.

Let us suppose that an electric central station has a load-factor of 20%, which is pretty fair in practice, that is, that the maximum load on the station is five times the average load, or, what is the same thing, that the actual output of the station is only one-fifth of what it would be if it could be run at 100% load-factor. Let us also assume that with this load-factor the fixed expenses of the station, including such charges as interest, depreciation, taxes, insurance and a proper amount for dividends, form 75% of the total expenses, not at all an unusual proportion, the remaining 25% of the expenses being due to the actual production of electricity. Further, let us assume ten cents as a fair average cost per kilowatt-hour, including both the fixed expenses and those directly due to the output, which latter we may call the running expenses.

If we now assume that the output of the plant increases five times, but in such a way that the maximum load on the plant remains as before, thus necessitating no further investment, then the fixed expenses will remain as before, viz., at 75% of the original total expenses, while the running expenses will have been multiplied by five, that is, they will now be 125% of the original total expenses, and the new total expenses will be 75% plus 125%, which is 200% of the old total expenses. In other words, the total expenses will have only doubled while the output will have been multiplied by five and the new average cost per kilowatt-hour will be only $\frac{2}{5}$ of the old cost, the fall in the average cost per kilowatt-hour being from 10 cents to 4 cents, or a reduction of 60%.

A load-factor of 100%, however, is of course utopian, and it is, therefore, perhaps of more practical interest to inquire into the effect of a smaller increase of load-factor, let us say, from 20% to 24%. The other assumptions being maintained as before, we have the fixed expenses as 75%, the new running expenses as 30%, and the new total expenses as 105% of the old total expenses, while the new output is 120% of the old. The new rate per kilowatt-hour will then be $\frac{105}{120}$ of 10 cents, that is, 8.75 cents, or a reduction in cost of 12½% due to an increase of load-factor from 20% to 24%. It will be seen then that but a comparatively small increase in the output of the average plant means a great saving in the cost per kilowatt-hour, provided always that this increase in output does not bring with it an increase in the maximum load on the plant so great that increased expenses due to new investment completely offset the advantage of the increased output.

As before stated, the above facts are pretty well appreciated to-day with the result that the more progressive companies have organized special " business getting " or " new business " departments with the prime object of increasing the market for electric energy, especially in those directions which will result in an increased output from the plant at those times when it would otherwise be running under light load. They usually strive to accomplish this by the use, among other ways, of personal solicitation of customers and by advertising, especially with a view to increasing the use of electricity for a variety of other purposes besides lighting. With most central stations, the maximum load on the plant or " maximum demand " is due to the lighting load, and any increase in the output for other purposes than lighting is pretty sure to have a favorable effect on the load-factor. In most cases a great deal has already been accomplished in the direction of selling electricity for power purposes and for sign work, and the pushing of its sale for cooking and heating purposes is now just beginning to be vigorously undertaken. The extension of the uses of electricity in these directions is bound to cause a reduction in its cost by the improvement in load-factor, and in turn this reduction of cost will permit lower prices with a resultant still further increase in its use. This again will be followed by improved load-factor and lower cost, or in other words, increased use and reduced cost will so act and react upon each other that a great extension of the demand for electricity will result.

One thing which should help to bring this result quickly will be the further introduction of new lamps of high efficiency such as the tantalum and metalized filament lamps already with us, and the even more efficient tungsten, helion, and other lamps which seem likely to come at a day not very far distant. The great reduction in the cost of electric lighting which will result from the use of these lamps will enable the community to spend more for electricity for other purposes, which will be followed by improved load-factor and consequently lower cost per kilowatt-hour.

For any particular electric light and power company, however, the reduction in the cost of a kilowatt-hour due to improved load-factor can be delayed or hastened accordingly as the company adopts a system of rates of charging for its product which does or does not tend to encourage desirable business, viz., business which, when obtained, will help to improve the load-factor.

This fact is also well recognized today by the majority of central station managers, but it is only within the last six or seven years, nevertheless, that its recognition has become at all general. At the present time an examination into the rates of electric light and power companies in this country will show that nearly all those in the larger cities, and a great many in the smaller ones, have adopted a system of rates designed to give the lowest rate per kilowatt-hour to those customers who help most toward the improvement of the load-factor of the station and the highest rate to those who help the least in that direction. Toward the accomplishment of this purpose, there have been two general and very distinct systems of rate making employed.

The first of these systems might be called the load-factor system, which system appears in various forms of which the fundamental principle of all is that the rate per kilowatt-hour to the customer depends on his individual load-factor; that is, on the ratio of his average load to the maximum load which he throws upon the station.

The second of the above-mentioned systems is known as the "two-rate" system* and the principle of it is to charge the customer a high rate per kilowatt-hour for electricity consumed during the hours of the day when the station is heavily loaded, viz., during "peak" hours, and to charge a low rate for the consumption during the hours of light load.

It is evident that either of these systems of rates will have a beneficial effect on the load-factor of the station, the two-rate system by directly encouraging the use of electricity at all times outside the peak hours and by relatively discouraging its consumption during the peak hours; and the load-factor system by encouraging the use of electricity during long periods of time each day, or in other words, by directly encouraging what are often spoken of as the "long-hour" consumers and by relatively discouraging the "short-hour" consumers.

Of these two systems of rates the load-factor system is the one which has survived the test of experience and it has been adopted in some form by almost all the prominent companies in the country. The two-rate system, in this country, at least, is nearly obsolete, and is, I am inclined to believe, made use of by a few companies only, and by them merely to take care of a few special customers. I will not, therefore, stop to discuss this system but will pass at once to the load-factor system, the discussion of which will constitute the remainder of this paper.

The simplest form of load-factor system is one under which each customer is charged a uniform rate per kilowatt-hour for electricity consumed, and in addition is charged per month, or per year, a certain amount per unit of his maximum demand, by which last term is meant the maximum load which he throws upon the station during the period in question. With a system of charge of this nature the average price to the customer of a kilowatt-hour will depend wholly on his individual load-factor.

For example, let us suppose that the rates are $3.00 per month for each kilowatt of maximum demand and 5 cents for each kilowatt-hour of consumption. If the customer's load-factor is 100%, it is equivalent to saying that his maximum demand is maintained continuously throughout the month, or for 730 hours, and in such cases the average cost of a kilowatt-hour will be found to be 5.4 cents. On the other hand, if the customer's load-factor is only 50%, his total consumption is equivalent to the use of his maximum demand for only ½ of 730, or 365 hours, and the charge of $3.00 per kilowatt of demand becomes a larger proportion of the total, resulting in a higher rate per kilowatt-hour, viz., 5.8 cents. With a 10% load-factor the $3.00 charge per kilowatt of demand becomes nearly 50% of the total charge and the rate per kilowatt-hour rises to 9.1 cents; and with still further lowering of the load-factor the rate per kilowatt-hour rises very rapidly and approaches infinity as the load-factor approaches zero. This is shown graphically in the diagram, in which the curve shows the variation of the average price of a kilowatt-hour with variation in the load-factor or with the number of hours use of the maximum demand, which is the same thing.

Now a simple load-factor system of the form described above is nothing more nor less than a combination of the two oldest methods of charging for electricity, namely the so-called contract or flat-rate method and the "uniform meter rate" method.

The contract or flat-rate method

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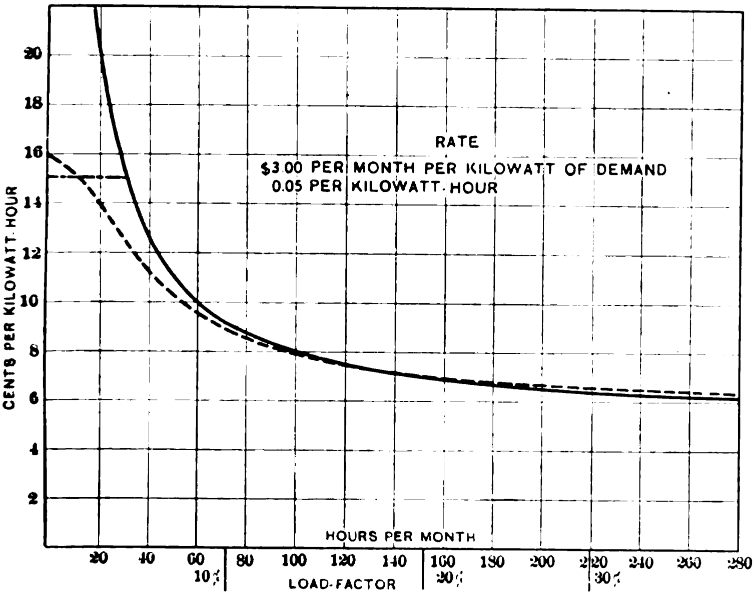
*There is a form of load-factor system sometimes called the "two-rate" which must not be confused with above, and will be referred to later.

consists in charging the customer a certain amount per month or per year determined by the current carrying capacity of his apparatus connected to the company's mains, that is, by his "connected load" as it is technically called; and since the connected load is evidently the maximum demand possible, a charge on it is analogous to the charge on maximum demand made with the simple load-factor system described above. In fact, a number of companies operating load-factor systems at the present time make the maximum demand charge on the connected load instead of on the actual maximum demand. The advisability or inadvisability of this practice will be discussed later.



The uniform-meter rate method consists in charging for actual consumption of electricity only, and at a uniform rate per kilowatt-hour to every customer, and this charge is evidently the same as the charge per kilowatt-hour with the load-factor system already described.

These two old methods of charging, when combined, form a load-factor system, as already stated, and have a desirable effect on the business; but either one alone has an undesirable effect. The contract method is the older and was used practically altogether in the early days of central station supply of electricity when there were no meters available. Its great defect is that there is no inducement to the customer to cut out apparatus, the use of which is not needed, with the result that there is great waste of current which, of course, keeps up the cost. In consequence of this defect the contract method of charging began to be replaced by the meter-rate method as soon as reasonably cheap and accurate meters began to come on the market. The contract method has now almost disappeared.

It did not take very long, however, after the introduction of the uniform meter rate method for it to become apparent that it was also very unsatisfactory. It gives the same rate per kilowatt-hour to the short-hour consumers, or those with low load-factors, as it does to the long-hour consumers, or those with high load-factors, thereby unduly encouraging the use of electricity by the former class and discouraging or actually prohibiting the use of it by the latter class, and consequently it has a very undesirable effect on the load-factor of the station.

The first attempt to improve upon the uniform-meter rate method of charging was to drop the uniform feature of it and to offer lower rates per kilowatt-hour in proportion to the quantity of electricity consumed, usually in the form of discounts depending on the size of the monthly bill. This was a step forward, for the reason that a large consumer is likely to be a long-hour consumer and consequently helps to give a good load-factor to the station. The fact, however, that the above, although very often true, is nevertheless not always so, is the very reason why a system of discounts for quantity is not satisfactory. It often happens that under it some large consumer is taken at a low rate per kilowatt-hour when the effect that he has on the operation of the station is to drive up the station peak, necessitating expenditure for additional machinery, or at least bringing nearer the day when the natural growth will necessitate such expenditure, and at the same time he does not increase the output of the station proportionately. Such a customer may actually increase the average cost of producing a kilowatt-hour.

At the present time the weight of opinion is strongly in favor of a load-factor system of charging; that is, I will repeat, a system combining a maximum demand and consumption charge; but generally in practice subject to certain modifications, both in substance and in form. These modifications are usually necessary and desirable, but they certainly add to the complexity of the subject.

The first modification is the addition of the wholesale discount, that is, a discount on bills over a certain size. This discount is justifiable and desirable when combined with a load-factor system, as there is no doubt that a large consumer can be supplied at a less cost per kilowatt-hour than a small consumer, and its addition to the load-factor system extends the range of the latter, making it possible to meet the competition of isolated plants by giving very low rates per kilowatt-hour to large long-hour consumers while at the same time the possibility of the large short-hour consumers also getting a very low rate per kilowatt-hour is avoided.

When wholesale discounts are given, they should be so designed that there will not be, under any circumstance, an inducement to the customer to waste current in order to secure the discount. For example, if a 10% discount is offered when the bill reaches $100, it means a net bill of $90; whereas if the bill had been only $99, there would be no discount. In the latter case, if the customer deliberately wasted current so as to add $1.00 to his bill, he would save himself $9.00. This difficulty can easily be avoided by making the discount apply, not to the whole bill, but only to the excess beyond the point where the discount is earned. For example, when the bill exceeds $100, a discount of 50% can be given on the excess only. With this method of discounting it will never pay to waste current.

Another modification of the load-factor system is the making of a "service" charge in addition to the charges on maximum demand and on consumption. To explain this charge, however, it will be necessary to go a little further into the theory of the load-factor system itself.

With the load factor system, as before stated, there are two charges, one on the maximum demand of the customer, the other on his consumption; and the assumption is that the bulk of the expenses incurred to supply each customer is proportional to these two quantities. This assumption is correct, the expenses proportional to the maximum demand and the consumption of the customer being from 60 to 80% of the total, but the remaining 20 to 40% nevertheless are not proportional in any way to the maximum demand and consumption of the customer. If, therefore, a strict load-factor system of charging is to be maintained, these expenses must be charged on the maximum demand, or on the consumption, or be divided between them in whatever way may seem expedient. If, however, we can find that the whole or a part of these expenses proportional neither to maximum demand nor to consumption are nevertheless proportional to some other quantities, then these other quantities can be with advantage made the bases of other charges, provided this does not cause too great complication or for other reasons is not practical. Now there are certain expenses which are the result merely of the fact that a customer has been connected to the company's mains, and these expenses are the same whether his maximum demand is high or low, his consumption great or small, or his load-factor good or bad. Such expenses are for clerical work in making out the bills and keeping the customer's account; for meter reading and for maintenance of service connection, and some companies have undertaken to make a direct charge to cover these, calling it a "service" or "customer's" charge.

One well known engineer managing several electric light companies has adopted for them a load-factor system of rates modified by a service charge of which the statement is as follows:

Maximum demand charge, $3.00 per kilowatt per month.

Consumption charge, $0.05 per kilowatt-hour.

Service charge, $1.00 per month.

Most companies, however, prefer to take care of these service expenses by charging them on the maximum demand and the consumption, and by establishing a minimum bill, usually a dollar or two a month.

We now come to the third, the last and the most important modification of the load-factor system, viz., the fixing of a maximum rate per kilowatt-hour. We see from the curve in Fig. 1 that as the load-factor of the customer falls off, the rate per kilowatt-hour rises, and approaches infinity as the load-factor approaches zero. There are, however, practically no companies using load-factor systems which charge the very short-hour consumers strictly on the basis of load-factor, but instead they fix upon a certain maximum rate per kilowatt-hour corresponding to a certain load-factor and give this rate to all customers with this load-factor or with less. In other words, when the curve reaches this maximum rate it is continued horizontally instead of rising in accordance with load-factor. In the diagram for example, the curve is shown by dashes as flattened at a rate of fifteen cents.

Before giving the reasons why it has become the practice to fix a maximum rate per kilowatt-hour with a load-factor system, instead of permitting the rate to vary strictly with the load-factor to all customers, it will be best to describe at this point another manner of expressing a load-factor system in which the fixing of a maximum rate is included. This is as follows:

The customer is charged a certain rate per kilowatt-hour, known as the "primary" rate, for a consumption of electricity equivalent to the use of his maximum demand for a certain number of hours per day or month, but should his consumption of current be greater than the above-mentioned amount, he is charged for all the excess at a lower "secondary" rate. For example, the rates might be as follows: 15 cents per kilowatt-hour, as the primary rate, to be charged on a consumption equivalent to the use of the maximum demand for 30 hours per month, and for all consumption in excess a rate of 5 cents per kilowatt-hour to be charged. These rates will be found to give a rate curve identical with the full curve in the diagram, except that it will not rise above 15 cents but will follow the horizontal line. It is, therefore, distinctly a load factor system except that a maximum rate per kilowatt-hour is fixed. This system is very widely used and in fact is the form of load factor system employed in a great majority of cases. It is sometimes spoken of as the two-rate system, but should not be confused with the two-rate system already described, and I shall therefore call it Wright's system after the name of its originator.

As already stated, Wright's load factor system includes the fixing of a maximum rate per kilowatt-hour, but with the simple load factor system, consisting of a charge on maximum demand combined with a charge on consumption, it is also usual to fix a maximum rate per kilowatt-hour either by a provision that the customer's bill shall not exceed ten, fifteen, or twenty cents, or whatever maximum rate per kilowatt-hour has been decided upon, or by offering the customer as an alternative to the rate as determined by load factor, a uniform rate per kilowatt-hour equal to the maximum.

Attention should here be called to the point that this fixing of a maximum rate per kilowatt-hour generally means that as far as the rate is affected by load factor the maximum shall not be exceeded, but does not mean that it may not rise above the maximum as the result of a service charge such as already described, either made direct or in the form of a minimum bill. For example, if a minimum bill of $1.00 per month is charged, and it happens no current is taken, then of course the rate per kilowatt-hour is clearly infinite.

There are a number of reasons for fixing a maximum rate per kilowatt-hour. In the first place, it is often a case of necessity, the maximum rate per kilowatt-hour being fixed by law, whether wisely or unwisely. Again the maximum rate having been fixed in some cases by the company itself prior to the adoption of a load factor system, it has been thought unwise to go above it, on account of the possibly bad effect on the feeling of the community, even though it might be thought that by not so doing some of the short-hour customers would be paying less than they ought to. It would certainly seem, if the rate curve shown in the diagram, for example, is properly based on the maximum demand and on the consumption, that the total charge to any customer would be at least approximately proportional to the cost of supplying him and that therefore if a maximum rate per kilowatt-hour is fixed, some of the short-hour customers will be taken at less than cost. If the following considerations, however, are taken into account, it will be realized that the rate per kilowatt-hour of the very short-hour consumers should not depend wholly on their load factor but really ought to be less than the curve would indicate.

The load-factor system has often been criticised for the reason that although it helps to improve the load-factor of the station by encouraging customers with high load-factors it fails to encourage those customers whose load factors are low but who nevertheless help the load factor of the station because they take their current at other than peak hours. This criticism of the load factor system is a fair one, but by the introduction of a maximum rate per kilowatt-hour it is largely avoided since this modification of the load factor system gives a reduced rate to that class of customers least likely to take current during the peak hours, viz., the short-hour consumers. It must be clear that if a large body of customers use their maximum demands but an hour or two a day, there is strong probability that their joint demands at the time of the station peak will be but a small fraction of their joint maximum demands. It follows that the short-hour consumers, as a class, are less likely to add to the station peak than the long hour consumers, and there is reason, therefore, for charging them less per unit of maximum demand. It is a difficult problem in the theory of probabilities to calculate what reduction the short-hour consumer should get, but it should certainly be a reduction increasing slowly at first with reduction in the number of hours use of the maximum, but finally increasing rapidly when the time of use is as short as one or two hours per day. Such a reduction in the rate per unit of maximum demand to short-hour consumers results, of course, in the average rate per kilowatt-hour being somewhat lower than that determined by load-factor alone, and the rate curve, instead of being like the full curve in the diagram, will follow the dotted line. It will be seen that the full curve can be made to very closely resemble the dotted curve if a proper maximum rate per kilowatt-hour is chosen.

Just where to fix the maximum rate cannot be accurately figured out, and its determination, therefore, is generally a matter of judgment. Sometimes it is fixed by law or by custom, as already stated, and sometimes it is placed lower than either law, or custom or economic desirability would require, merely because a low maximum rate tends toward simplicity since it allows a large proportion of the customers to be taken at a simple uniform rate per kilowatt-hour, and also because of its effect on public opinion. It is the maximum rate per kilowatt-hour which the public sees; and a high one, even if economically desirable and just, is likely to stir up trouble.

I have now described the load-factor system with those modifications which I believe represent the best practice to-day. I should like very much now to take up and describe some of the load-factor systems actually in use in order to show their fundamental similarity even when superficially appearing very different but time will not permit, and I must pass on, therefore, to the conclusion of this paper, namely the methods of determining the customer's maximum demand and consumption.

The latter can be disposed of in a few words. The unit of consumption now generally used is the watt-hour or its multiple the kilowatt-hour, and it has almost entirely superseded the ampere-hour. The method of determining the consumption is by direct measurement with a watt-hour meter.

What should constitute the maximum demand of a customer and how it should be determined, however, are questions which cannot be answered in a few words. There are great differences of opinion and practice in regard to them.

It is the practice of some companies to assume, as I have already stated, that the customer's maximum demand is the maximum demand possible, which is, of course, the connected load. This assumption, however, is in a majority of cases incorrect, and when incorrect is undesirable, as it is the actual maximum load thrown upon the station by the customer which affects the station output and load-factor; and the number of lights, motors or other apparatus connected, if they are never in use simultaneously, is of little consequence. Furthermore, the use of the connected load as the basis of charge discourages the extensive use of electricity. If a customer is to be charged for every additional piece of apparatus connected, he will be inclined to connect as few as possible and may even use electricity in certain parts only of his premises and in other parts use other means of obtaining light and power. In the case of motors, the customer will be likely to install them as small as he thinks he can possibly get along with, the result perhaps being overloading with consequently poor service and dissatisfaction.

It is safe to say, however, that there are but a very few companies in the United States to-day which make use of the full connected load as a basis of charge. There are a number that appear to do so, if we judge by their printed forms of contract with customers, but if investigation is made, it will be found in almost every case that the word "lights," installation," or "h.p." occurring in the contract form is not taken to mean "all the lights," the "total installation," or "rated horse-power," but is really the customer's maximum demand either estimated, or measured by an instrument.

The estimated demand is used as the basis of charge by many of the companies which appear to be using the connected load, and there are other companies which clearly make the estimated demand the basis of charge even in their printed contracts. The principal objection to the practice is, of course, that the estimate is liable to be inaccurate. In the smaller companies a separate estimate can be made for each customer, but in the larger companies it is hardly practical to do this, and it is, therefore, usual to assume the average maximum demand for each class of customers; as, a certain percentage of the connected load, as for example, 40% for residence lighting, 75% for store lighting, and so on. When such estimates are made with care by actual measurements in numerous cases they may be considered to be fairly accurate, at least at the time they are made, but in all probability the average maximum demands of the different classes will not remain constant and the estimates, therefore, will cease to be of value. Further, even if the estimated average maximum demands have a high degree of accuracy it must be remembered that after all they are merely averages and it is quite possible that the maximum demand of any particular individual may be considerably higher or considerably lower than the average of his class, and consequently his rate will be either too high or too low.

There are other objections to the use of the estimated demand which are practically the same as for the connected load basis, since the estimate must be based on the connected load. At the beginning of a contract with a customer it is of course practicable to determine the connected load by inspection. The number of outlets can be counted, the candle-power of the lamps or the capacity of other apparatus connected to each outlet can be noted, and in this way the connected load ascertained but after the connected load is once ascertained it becomes necessary to require the customer to agree to make no change in his installation without notifying the company. Such a requirement is objectionable, inasmuch as it seriously impairs one of the great advantages of electricity, viz., its flexibility of use. The customer cannot change the candle power of his lamps, substitute a fan or heating device in place of a lamp, nor connect apparatus to an outlet nor in use before without consulting the company. Furthermore, in spite of agreements to the contrary, a customer either wilfully or through ignorance of his agreement will often make changes without notifying the company and the latter has no means of knowing when this is done unless frequent inspections of the customer's premises are made. Such inspections are an intrusion on the privacy of a customer and are sure to be an annoyance to him. Also, if they are made frequently enough to be of any use, they become a heavy expense to the company.

Measuring the customer's demand with an instrument is a practice which has numerous advantages, the first and most evident of which is that the demand can be obtained with accuracy. Further, a customer can freely make changes in his apparatus installed without stopping to notify the company as his demand will be recorded on the instrument. For the same reason no inspections of the customer's premises are necessary other than the ordinary ones to see if the installation is safe and that no connections are made back of the measuring apparatus. The maximum demand indicator also acts as a guide in determining the proper size of watt-hour meter, and if this information leads to the use of smaller watt-hour meters there may be a considerable reduction made in the loss due to their slow running or stopping when operating on light load. Another advantage of the measured demand is that the customer need not hesitate to connect as much apparatus as he wishes. The demand indicator will show only the power supplied to such apparatus as may be simultaneously in actual use.

The disadvantage of the measured demand is, of course, the necessity of using an instrument. This means, in the first place, the expense of purchasing and installing and afterwards expense of maintaining reading and resetting. Also additional resistance is introduced into the line, absorbing energy and injuring regulation. Still these arguments could also be urged against the use of a watthour meter, and they are not valid if in the actual instruments used these objections are reduced to a minimum, which is the case. Demand indicators with capacity up to 25 amperes can now be purchased for close to $6.00 and even large instruments of several thousand amperes capacity cost only about $30 or $40. In addition they are simple to install, cost very little for maintenance and absorb but a trifle of energy.

If the customer's maximum demand is to be measured, however, the question will arise as to just what shall constitute this maximum demand, and this question is a difficult one and one about which there is the greatest difference of opinion. Perhaps the best way to consider the question is as follows:

The maximum demand charge may be looked upon as in the nature of a rental charge for the electric power held ready to furnish the customer at any moment he may call for it by the turn of a switch. The power may be rented by the year, the month, the week or the day, as the case may be, the rate for the longest period being of course the lowest. The case of a room in a hotel for which you pay $2.00 per day, but only $10.00 per week is analogous.

The customer then, who rents power by the year gets it at the lowest rate, and the amount of power to be paid for is the maximum demand during the course of the year, shown by the highest reading of the demand indicator. It is clear, however, that if a customer is not going to use his annual maximum demand very frequently, it will not pay him to rent power by the year, any more than it would pay him to take a hotel room for a year unless he were going to use it regularly. In such a case it would be better to rent power by the month, the amount to be paid for being taken as the maximum demand for the month, as shown by the monthly reading of an indicator. Still again the customer's demand for power may vary so greatly from day to day that he really cannot afford to rent power by the month, but should instead rent it by the day, the daily readings of the maximum demand indicator being taken as the basis of charge.

If the question is looked at in the above light, I think that the opinion of those who claim the indicator should be read annually can be reconciled with the opinion of those who claim it should be read monthly or with the opinion of those who claim neither method is satisfactory on account of the variation in demand from day to day. There seems to be no reason why power should not be offered both by the year and by the month, or even by the day. There is one large company at least which seems to consider this in its rates and offers a yearly lighting contract in which the charge on maximum demand is based on the annual reading of a Wright Demand Indicator, while for those customers who take current only from month to month the maximum demand is taken as the monthly reading of the indicator.

There is one point which must be mentioned in connection with the measured demand when taken as the highest reading of a maximum demand indicator for the year, which point is, that until the readings can be taken the demand must be estimated. This, however, is only necessary in the case of new customers and is not a serious matter in any case as the estimate only has to be used but a few months as a rule and in no case for more than a year. With old customers whose demand has been fixed in the year just passed, this demand can be continued in force until the new measurements are obtained

Some companies combine the measured demand with the estimated demand, using demand indicators to check doubtful estimates, or as a means of detecting an unwarranted extension of connected load. With this method the indicator is not necessarily permanently installed, but may be moved about from one customer to another.

Still another practice is to determine the maximum demand by agreement with the customer and then to make it impossible for him to exceed this demand. As it would not be expedient to use any means of limiting the customer's demand, which would actually cut off his service, such as circuit breakers or fuses, the limiting is usually done, if practicable, by means of a device which will cause his lights to flicker the moment the agreed upon demand is exceeded and will allow service to be restored when excess is cut out. This practice, as compared with the measured demand, has the advantage of positively determining the demand in advance, and it avoids the indicator readings necessary with the measured demand. It has the disadvantage of causing irritation when a customer on an occasion wishes to exceed his demand and finds he cannot do so. The owner of a large residence would probably resent any interference with the use of such lights as he might at any time turn on and it would nevertheless be difficult to make him agree to a demand very much higher than what he usually expected to have. On the other hand, it may be said that many small customers would prefer to have their demand fixed and thus be prevented from inadvertently exceeding it, thereby raising their bills. It would seem, therefore, that a judicious use of both the measured demand and the limited demand methods of charging might be found advantageous. For example, the measured demand could be made the regular practice, but the option of the limited demand might be given. A flickering device, however, could not be used on power or arc light installations, nor even on large installations of incandescent lamps.

In the foregoing discussion of the load-factor system of charging, I have considered its desirability from an economic standpoint, *i.e.*, I have tried to show that it tends to reduce cost just as really as does an improvement in the efficiency of generating or transforming apparatus. I want now to say a few words in regard to its justifiability from the point of view of the public. The fact that the load-factor system tends to reduce cost is at once a justification in so far as the public ultimately benefits by the reduction, but it is nevertheless very likely to be criticised by the consumers and the public in general on the ground that different rates per kilowatt-hour to different customers constitutes discrimination. This idea, is of course, founded on a misconception, viz., that the cost of rendering service is proportional to the number of kilowatt-hours sold. There is, as a matter of fact, as I believe I have already shown, but a slight relation between the two. Every central station manager would say at once that it costs much less to furnish current to one lamp for ten hours a day, than to ten lamps for one hour in spite of the fact that the consumption of current in each case is the same; and, that generally speaking, it costs less per kilowatt-hour to furnish current to a long-hour consumer than to a short.

This misconception of the public must, however, be reckoned with and should be met by a campaign of education, rather than by a policy of concealment. Neither is it any longer good policy to give special rates to individual customers even if these special rates are in themselves justifiable. To avoid special rates, however, it is necessary to develop some system which will cover every case and automatically give the proper rate per kilowatt-hour to each customer. With a load factor system this can be done and there are actually a few companies to-day, I believe, which have published rates taking care of all customers—great and small—long-burning and short-burning. If they do not deviate from these published rates, they are in a strong position to defend themselves against charges of unjust discrimination, even though the result may be that the rate per kilowatt-hour to different customers may vary within wide limits.

DISCUSSION

R. S. **Hale**: Mr. Codman puts many of the facts relating to the electric rate problem in a new and interesting light. Even if some of his paper is old, it is interesting to the profession and instructive to the public. The load-factor and other systems of charging for electrical energy are based on exactly the same principles that are used in practically every other business; but because the electricity supply business is comparatively new, the public is apt to feel that these various systems are unfairly and unwisely complicated. For instance, I was recently talking on this subject with a lawyer who had been concerned in some hearings on rates before a legislative committee. He spoke of the Wright demand system, whereby a high price is charged for a certain number of units and a low price for the balance, as being something most unusual. I then asked him how he paid for the stenographic reports of the proceedings. He said, "The price is 15 cents per hundred words for the first copy and 5 cents per hundred words for additional copies." That is, he was paying for his copies of the proceedings on exactly the same system as that used in the electricity supply business.

It is said that under these different systems one man may pay 2½ cents a unit for his current and another man may pay 15 cents; this ratio of 6 to 1 is said to be most unusual and unfair. The same man will send a pound of circulars to San Francisco paying at the third-class rate, or at the rate of eight three-thousandths of a cent per pound per mile, while he mails a letter to Cambridge or South Boston for 2 cents, or at the rate of 32 cents per pound per mile; the ratio here instead of being 6 to 1 is something like 10,000 to 1.

Not only must the various conditions that Mr. Codman speaks of in his paper be considered, but there are numerous others that have to be considered in order to make a fair price. Most companies supply a fairly uniform district, but there is no question that it costs very much less to supply the same quantity of electricity delivered at one point than it costs to supply the same quantity delivered at many scattered points. In some cases this can be taken care of by a wholesale discount, but it is obvious that the wholesale discount does not always take care of the situation. The Massachusetts gas commission have in their decisions recognized the principles that a company supplying scattered districts should charge more per unit than a company supplying a densely populated district. If now the same company should supply both districts, this would make no change in the physical or financial conditions that would warrant charging a uniform price, unless perhaps the saving by consolidation had been sufficient so that the lower price could be adopted as the uniform one over both districts; but this would hardly be fair, as it would result in giving the whole advantage of the consolidation to the district with a scattered population.

Another feature of service that warrants a differential price is the question of quality of service in the broadest sense. The particular item of which I am now thinking is the question of overhead and underground supply. The cost of underground supply is of course very much greater than of overhead supply, but if the underground supply is in a densely populated district and the overhead supply in a scattered district, these two differences may balance so that the total cost is the same. Now, however, suppose that a scattered district insists on an underground supply. This of course at once runs up the cost very much, and it is only fair that this district should pay for it rather than that the whole population served should pay for it.

It has been suggested, and the plan has been put in operation in one of the English municipal plants, that instead of making the whole charge proportional to the current, there should be a charge proportional to the valuation of the property supplied, plus a small charge for current. Such a system might work out very satisfactorily, since it is usually the districts where the valuations are high and the houses are of good quality that underground supply is insisted upon. Even without the question of underground or overhead, supply, there is a very distinct difference in the cost of installation in districts of different valuations. A rich district where the houses are expensive and handsome insists upon much more sightly poles and neater and more expensive construction than does a poor district.

While the maximum demand and the load-factor and the total supply are usually the chief items in determining the cost, yet sometimes it is a short cut to classify customers according to the nature of their business rather than according to some electrical quantity. For instance, in the telephone business they very early realized that a frequently used telephone costs much more than one used infrequently. It also is true that a residence telephone is both used and called up much less frequently than a business telephone. It was therefore entirely reasonable to make a difference in price between residence and business service.

In like manner the municipal water plants and the water companies usually make a difference in price according as to whether the water is to be used in a residence or in a factory, although the same water is supplied in both cases.

The most essential thing in all these questions of rates is that whatever differentials and double rates and classifications are made that there should be no unfair discriminations. The Government charges one rate for first-class mail, another rate for second-class mail, another rate for third-class, another rate for registering, another rate for special delivery, and so on; but no matter who you are, you get the same service for the same price under all circumstances. In the same way the railroads carry passengers for 20 cents a ton-mile, industrial product for 5 or 6 cents a ton-mile, and down as low as a quarter of a cent a ton-mile; but everybody ought to pay the same price in each case. There should be no unfair discrimination.

Electric light companies must realize

that they are public service corporations and that they must charge the same price to everybody for the same service. This result cannot be obtained by any simple system of rates except at a great cost to the public. If, for instance, the Government should adopt the principle that it must charge the same price per ounce per mile for all service, the result would obviously be bad for the public. If the railroad companies should charge the same price per ton-mile for all service the result would obviously be bad for the public. If the electric light companies had to charge the same price per kilowatt-hour the result would likewise be bad for the public.

If the same company is going to supply different classes of service, it must have differential rates to differentiate between these services just as the Government has differential rates for the postal service, just as municipal water works have differential rates for the supply of water, just as the railroads have differential rates for all their business. You can find no business whatsoever that has a simple uniform rate, unless it be a business that supplies only a single article in a single quantity. The electric companies must face the situation that they must have differential rates, that these rates must be fair to all in proportion to the service rendered, and that in order to obtain these results all rates must be open and public and the same to all for the same service.

First Atlantic Cable

A very interesting story by Mr. Mullaly, of the laying of the first telegraph cable across the Atlantic Ocean appeared in the February and March issues of the Journal of the Franklin Institute of Philadelphia. The immense importance of this work, the expense involved, the difficulties encountered and overcome, and the graphic manner in which the incidents are described, unite in making a delightful sketch in electrical engineering history.

Local Organizations

ARMOUR INSTITUTE

At the meeting of the Armour Institute Branch held on March 8, in the physics lecture room, Mr. Charles Jones, chief engineer of the Aurora, Elgin, and Chicago Electric Railway, gave a very interesting talk on " Some Experiences in Electric Railway Building." In his paper Mr. Jones pointed out many of the necessary qualifications of the successful engineer. His paper was of exceptional interest and held for two hours the attention of the ninety members and visitors present.

The subject of discussion at the April 5, meeting of this Branch was " The Electric Motor versus the Steam Locomotive." Mr. M. V. Stagg gave a digest of the Institute paper by Messrs. Stillwell and Putnam. Mr. H. R. Badger discussed " The Electrification of the West Shore Railway " his discussion being illustrated with lantern slides.

Mr. C. S. Henning discussed the subject of " Multiple-Unit Control." Mr. T. A. Banning spoke on the methods of placing jumpers on the third-rail at grade crossings, and Mr. J. E. Saunders added a short discusssion on the method of connecting the signal system to the track circuit in the base of the bonded rail for the return power circuit.

A meeting of this Branch was held on April 19 at Armour Institute with an attendance of thirty. Vice-chairman Ned. M. Sturgess presided and J. C. Hail acted as temporary secretary. J. E. Saunders gave an original paper on " Automatic Electric Signals," in which he pointed out the advantages of this system of railway signaling, and explained the functions of the various circuits of the system for both steam and electric roads. E. W. Adams '08 added a discussion on the " Train Staff System of Signaling. "

UNIVERSITY OF ARKANSAS

A meeting of this Branch was held on March 27, at Fayetteville, Arkansas,

W. B. Stelzner presiding. Mr. M. F. Thompson presented an original paper, "Winter Tests on Meters;" and an original paper was presented by Mr. J. R. Belknap. Mr. Edwards read an Institute paper.

Another meeting of this Branch was held April 3, with a total attendance of 50. Professor C. G. Carroll presented a paper on the "Arrhenin's Theory of Electric Dissociation," and Mr. O. E. Hicks read an Institute paper. Impromptu remarks were made by Professors Perdue, Marinoni, Morrow, and Brough.

Another meeting of the Branch was held April 17, with a total attendance of 43. A very interesting paper and some experiments on magnetic fields and high potential and high frequency was presented by Professor Gladson.

BALTIMORE

At the meeting of this Branch held March 15, at Johns Hopkins University, with a total attndance of 43, Dr. J. B. Whitehead presiding, the proposed new Constitution was discussed. The chairman strongly urged a full vote on the part of the Baltimore members. The chairman also reported on the work of the Committee on Increase of Membership.

Mr. S. D. Black, of the Rowland Telegraphic Company, read a paper on "Individual Motor Drive for Machine Tools." The paper, after pointing out the various methods of speed variation, took up the shunt field control of the interpolar motor. The paper dealt particularly with the experience in the Rowland telegraphic shops.

Another meeting of this Branch was held April 12, with 80 in attendance. The chairman called attention to the letter of Mr. Paul Spencer, chairman of the Committee on Local Organization, concerning the adoption of the proposed Constitution. The secretary was instructed to send a notice to each member of the Branch, pointing out the desirability of voting on the question.

Mr. P. G. Burton, of the Washington Branch, read a paper on the "Evolution of the Telephone Plant." This paper was an amplification of the one recently read in Washington, at which time an abstract appeared in the Proceedings. Mr. Burton's paper was received with much interest and upon its conclusion the Branch adopted a vote of thanks to the author.

BOSTON

At the meeting of this Branch held March 20, there was a total attendance of 73. A paper was read by J. S. Codman on "Rates of Charge for Electricity and their Effect on Cost."

[This paper and the discussion on it are printed in this issue of the PROCEEDINGS.]

Another meeting of this Branch was held April 17, with a total attendance of 127. A paper entitled "A Comparison of the Puyallup and Taylor's Falls Hydroelectric Systems" was presented by J. F. Vaughan, engineer with Stone and Webster, Boston.

CHICAGO

At a meeting of this Branch March 26, a paper on "High Voltage Alternating-Current and Direct-Current Railway Systems," was presented by W. J. Davis, Jr., railway engineer of General Electric Company, Schenectady, N. Y.

[This paper and the discussion on it will be printed in the May, 1907, PROCEEDINGS.]

The following list of meetings comprises the programme for the rest of the season.

Friday, April 26, 1907. "Electric Transmission Towers," by D. R. Scholes, chief engineer, Aermotor Company, Chicago.

On Friday, May 24, 1907. The American Institute of Electrical Engineers High-Tension Transmission Committee, will hold their meeting in Chicago, under the charge of Mr. Ralph Mershon, of New York, chairman of the committee.

Tuesday, June 11, 1907. "The Application of Large Gas Engines to Electrical Units," by E. T. Adams, general manager gas-engine department, Allis-Chalmers Company, Milwaukee.

UNIVERSITY OF COLORADO

At the meeting of this Branch held last month, Mr. Jenkins, instructor in electrical engineering presented a paper on "Practical Hints to Electrical Engineers," and Mr. N. F. Hanley a paper giving instructions as to note taking and what might be expected to be seen on the inspection trip.

CORNELL UNIVERSITY

The regular meeting of the Cornell University Branch was held on April 16, 1907, in the main lecture room of Franklin Hall. Dr. Steinmetz' paper on "Lightning Phenomena in Electric Circuits" was abstracted by Mr. J. C. Peebles, Professor Creighton's paper on "New Principles in the Design of Lightning Arresters," by Mr. E. D. Payne, and the secretary gave the results of the paper by Messrs. Rushmore and Dubois on the "Multigap Lightning Arrester." All the abstracts were prepared and delivered in accordance with the suggestions of Professor Geo. Shaad in the February number of the Electric Journal. The advantages of a systematic method of abstracting papers were demonstrated. The meeting proved to be one of the most interesting of the year, and after the abstracts of the papers had been delivered a large number of local members took part in the discussion. Ninety members and visitors were present. Following the discussion a number remained for an informal smoker and further conversation regarding technical matters.

UNIVERSITY OF ILLINOIS

A very interesting meeting of this Branch was held April 10, with an attendance of 26. The Branch was fortunate in having men to read and discuss the papers who have themselves made some study of the phenomena on which the papers were written. The following papers were presented:

"Alternating-Current Electrolysis," by J. L. R. Hayden; abstracted by W. W. Stifler of the physics department.

"Electrolytic Corrosion of Iron and Steel in Concrete," by A. A. Knudson; abstracted by A. T. Lincoln of the electrochemical department. Also discussed by Professor A. N. Talbot of the theoretical and applied mechanical department. The two papers were discussed together, and much interest manifested. The next regular meeting will be held May 1. At this meeting the officers for the ensuing year will be elected.

IOWA STATE COLLEGE

A meeting of this Branch was held on March 6, at which the advisability of drawing up a new constitution for the Branch was discussed. It was decided to leave the matter in the hands of a committee.

The paper of the evening was given by Mr. M. O. Bolser on "Magnetic Hysteresis." This paper involved some personal ideas on the theory of hysteresis on the part of Mr. Bolser.

On March 14 the executive committee met for the purpose of drawing up a new constitution. It was decided to present the proposed constitution before the members of the Branch at the next meeting.

On March 20 a meeting was held at which two original papers were presented, one by Professor L. C. Hodson, on "Electrolytic Processes" and the other by Mr. G. E. Marsh, on "Electric Furnaces." Both papers were illustrated with lantern-slides.

The proposed new constitution was presented before the Branch at this meeting to be acted on at the following meeting.

MINNESOTA

At a meeting of the Minnesota Branch in the offices of the St. Paul Gas Light Company, March 8, 1907, a committee of three members, Messrs. J. C. Vincent, C. L. Pillsbury, and F. R. Cutcheon was appointed to work with the Institute committee on increase of membership in the local territory.

The membership of the Minnesota Branch has nearly doubled during the last eighteen months, and a healthful interest is shown in all the Institute work.

The secretary announced the result of a postal and ballot on the best night for the meetings of the Branch and the meeting ratified the selection of the second Monday after the New York meeting, in substitution for the first Friday.

The subject for the meeting was "Electric Power Transmission," J. C. Vincent presented a paper outlining a method of reducing operating costs in a steam plant for comparison with water power. A number of curves were shown, giving results to be expected in a modern station. E. H. Scofield in discussing this paper showed that under the conditions of street railway load-factors and coal at ten cents per million B.t.u., water power operating in parallel with steam could be worth 0.6 cents per kilowatt-hour on peak loads instead of 0.2 cents where the steam takes the peaks. He referred to this as an illustration of the possible value of a water power of small flowage but with storage capacity sufficient to retain all the water for use on peaks.

F. R. Cutcheon followed with a paper dealing with the development of the Apple River, Wisconsin, which drains about 3000 sq. miles. He gave considerable data concerning this stream and the cost of its development.

A meeting of the Minnesota Branch, April 1, 1907, was devoted to a discussion of "Railway Electrification." Edw. P. Burch opened the subject with a review of the recent Institute paper by Messrs. Stillwell and Putnam.

He emphasized the superiority of the electric motor over the steam locomotive by calling attention to some of the weaknesses of the latter; among these that at slow speeds, as in climbing grades and starting, the steam locomotive is inherently unable to develop but a small portion of its full capacity and this at a time when a maximum output is highly desirable. In winter in northern climates, serious delays are caused by condensation and low evaporation; these materially reduce the available capacity of the locomotive when obstruction from snow demands additional power. On the other hand, the capacity of the transmission systems and of the motor is increased by cold. On branch lines the dead weight of trains can be greatly reduced, inasmuch as with electric locomotives, the tender often amounting to twenty per cent. of the train weight, would be dispensed with, while if the motors were mounted directly on the car trucks thirty to forty per cent. of the dead weight of the train would be removed.

As an illustration of the damage done by unbalanced locomotive parts, the speaker stated that on a single division of the Great Northern Railway during the last winter forty-five broken rails had been attributed to this cause.

Mr Burch favored 12½ cycles as a standard for single-phase work. E. H. Scofield brought up the point that even though a standard frequency were not immediately adopted, equipment could be interchanged without great inconvenience, since the single-phase motor can operate on various frequencies or on direct current with slight differences in efficiency and capacity.

J. C. Vincent did not consider that the tests on coal consumption by locomotives made at the St. Louis Exposition and quoted by Mr. G. B. Henderson, could be regarded as comparable with actual service results, these tests being made in a closed building and under favorable conditions.

An invitation was extended to the Branch, by Professor B. F. Groat to hold a meeting in the School of Mines building, University of Minnesota, on April 15. This invitation was unanimously accepted. The program committee announced that the subjects for the meeting would be "Electrolysis" and "Water Power."

Another meeting of this Branch was held on April 15, at Minneapolis, presided over by Mr. Barry Dibble, secretary, with a total attendance of 71. A paper entitled "Water Power Developments on the Pacific Coast," was presented by Professor B. G. Groat. The recent Institute papers on Electrolysis were also discussed.

UNIVERSITY OF MISSOURI

At the meeting of this Branch held March 15, with an attendance of 24, the Institute papers on "Alternating-Current Electrolysis" and "Electrolytic Corrosion of Iron and Steel in Concrete," were discussed.

On April 5 this Branch held another meeting with an attendance of 17, and further discussed the Institute paper on "Electrolytic Corrosion of Iron and Steel in Concrete;" also "Some Theoretical Notes on the Reduction of Earth Currents from Electric Railway Systems by Means of Negative Feeders," by George I. Rhodes.

At another meeting of this Branch, April 19, the paper by C. P. Steinmetz on "Lightning Phenomena in Electric Circuits" was discussed.

PHILADELPHIA

This Branch held a meeting March 11, at the Engineers' Club, W. C. L. Eglin presiding, with a total attendance of 76. A letter from the chairman of the Committee on Local Organizations, referring to the new proposed Constitution was read. The subject for the evening was "Marine Applications for Electricity," and papers covering various phases of that subject were presented respectively by Lieut-com. S. S. Robinson, United States Navy; H. M. Gleason, Assistant Naval Constructor United States Navy; and J. W. Kellogg, of the General Electric Company.

At the meeting of this Branch held April 8, with 78 in attendance, an address was delivered by C. W. Pike on the new proposed Constitution, after which the following papers were presented:

"Demonstration of Strictly Constant Motion and Frequency," by Dr. E. F. Northrup, discussed by Messrs. Snook, Thos. Spencer, Hering, and Breed.

"The Telharmonium," by J. W. Kelly, Jr. Discussed by Messrs. Snook, Hering, Breed, Ehret, Northrup, Eglin, Thos. Spencer, Gravel.

PITTSBURG

At the meeting of this Branch held March 12, with an attendance of 36, the papers presented were, "A Simple Method of Ruling Parallel Lines at any Desired Distance Apart," by Mr. H. W. Fisher; and "Some Interesting Facts relative to Selenium Cells" by Mr. R. A. L. Snyder.

At the meeting of this Branch April 9, 85 attended, and listened to the paper on "Motor-Generators and Synchronous Converters," by P. M. Lincoln, and the paper on "The Practicability of Winding Large Generators for 20,000 Volts," by B. A. Behrend. The discussion on these papers was opened respectively by Mr. P. M. Lincoln and Mr. C. E. Skinner.

PITTSFIELD

A meeting of this Branch was held March 14, at the Berkshire Auto Club, presided over by Mr. H. L. Smith, with an attendance of 18. Two Institute papers were reviewed: "The Current Transformer," by Mr. Kenneth L. Curtis; abstracted by Mr. E. A. Bessey; and Dr. Steinmetz' paper on "The Transformation of Electric Power into Light," abstracted by Mr. W. H. Jones.

The meeting of April 18, was held at the Hotel Wendell, Gilbert Wright presiding, with an attendance of 26. Members were strongly urged to vote on the proposed new Constitution. Mr. H. W. Tobey gave a very interesting talk on the "Electrification of the New York Central Railroad." His remarks were illustrated with lantern-slides.

PURDUE UNIVERSITY

A meeting of this Branch held March 19, at the electrical building of Purdue University, presided over by G. B. Walker, vice-chairman, brought out an attendance of 136. Mr. W. T. Small presented a paper on the subject of "The Mercury Arc Converter," dealing with its theory, manufacture, practical applications, and testing. Actual demonstration with a converter illustrated its practical application.

The meeting of April 16, under the same auspices, was attended by a total of 86. An address was given by Professor J. W. Esterline, his subject being "Seeking, Obtaining, and Holding a Position."

ST. LOUIS

The meeting of the St. Louis Branch of the A.I.E.E. held on Wednesday evening, March 13, was, with one exception, the best attended meeting of the Branch has yet held.

Professor F. E. Nipher, professor of physics at Washington University, delivered an address on "The Nature of the Electric Current." It was pointed out that there is still much uncertainty as to whether a current of electricity in a wire is a unidirectional flow of charged particles of one sign, or whether it consists of a flow of oppositely charged particles in opposite directions. Professor Nipher described certain experiments which he is about to undertake to study this point, the experiments involving a repetition of the Wheatstone measurement of the velocity of an electric discharge from a Leyden jar, with some modifications suggested by recent investigations of the discharges from radium.

The chairman announced that the executive committee had prepared an attractive programme for the remaining meetings of the year, which included one or more addresses by prominent members of the Institute living in other cities.

A regular meeting of the St. Louis Branch of the Institute was held on Wednesday evening, April 10, in the rooms of the Engineers' Club, with an attendance fully up to the high mark that has been maintained for some months past. This feature, combined with the readiness with which original papers have been secured, has had a noticeably stimulating effect upon the membership.

Mr. H. Weichsel, of the Wagner Electric Mfg. Co., presented an original paper on "The Overload Capacity of Synchronous Motors." The subject matter of the paper was largely mathematical, but there was developed a circle diagram for representing the operation of the motor, by which the maximum output could readily be determined. An expression for the overload capacity, as a function of normal capacity, was derived in terms of the ratio of field ampere-turns to armature ampere-turns.

Mr. J. H. Hunt, Instructor of Electrical Engineering at Washington University, presented the results of an investigation of the effect of varying power-factor upon the rating of synchronous converters. The expression giving this rating may be found in many text-books for the special case of unity power-factor, which is, of course, the usual operating condition in most installations. Mr. Hunt's results, however, show a surprising reduction in capacity as the power-factor is reduced.

At the May meeting a paper on "Insulating Varnishes and Compounds" will be presented by Mr. J. J. Kessler.

SCHENECTADY

On the evening of March 8, the Schenectady Branch gave a "Scientific Smoker," which was attended by nearly the full membership. It was held at Odd Fellows' Hall, which was taxed to its utmost capacity to accomodate the members and guests who listened to the following program:

Selection	Orchestra
Introductory	Dr. C. P. Steinmetz
Plans for Future	Mr. D. B. Rushmore
A Little Hot Air	Mr. C. H. Hill

Some Stunts Mr. E. B. Merriam
Reminiscences Mr. E. B. Raymond
Something Doing Mr. A. V. Thompson
Selection Orchestra

Cigars, pipes, and tobacco, and other refreshments were supplied to those in attendance and a specially interesting evening enjoyed.

On March 18, Mr. S. D. Sprong, of the New York Edison Company, gave an interesting address on the "Lighting System of New York," illustrated by the stereopticon. Mr. Sprong gave a history of the New York Edison Company, and followed with a detailed account of the system of distribution in sub-stations and protective devices to prevent shutdowns, etc. The discussion following the lecture was opened by Mr. C. W. Stone, of the General Electric Company.

On March 21, Mr. Richard Fleming, of the Lynn Works, General Electric Company, gave a lecture on "Arc Lighting," showing many new designs of special lamps and illustrating his lecture by actual apparatus and by lantern-slides.

On March 28, Mr. C. W. Larson of the power and mining department, General Electric Company, gave an illustrated lecture on "Mine Locomotives and Mining." Mr. Larson explained the modern methods used in mining operations, with special reference to the introduction of electric locomotives in this work. The special type of locomotive developed for use in confined space in mines contains many modifications for the economy of space, which formed the subject of a very interesting series of lantern-slides.

On April 4, Messrs. Steinmetz, Rushmore, Creighton and DuBois abstracted their papers which were read before the New York meeting of the Institute on March 29. Opportunity was thus given to the members to discuss further this interesting subject.

On April 11, Mr. G. H. Hill of the railway engineering department, General Electric Company, was scheduled to give a talk on "Multiple-Unit Train Control," but owing to the death of General Eugene Griffin, this lecture was postponed until April 18.

On that date, Mr. Hill lectured before an exceptionally large audience, and illustrated by lantern-slides the history and present status of various systems of large motor car and train control now in service.

SEATTLE

At the regular monthly meeting held Saturday evening March 16, 1907, the matter of holding a convention in Seattle at the Alaska Yukon-Pacific Exposition in the summer of the year 1909 was discussed. A letter was read from Secretary Ralph W. Pope, who had conferred with President Sheldon and the chairman of the Committee on Papers, in regard to holding the annual convention in Seattle during that year. As Seattle is so far away from the geographical center of the Institute, it is probable that this idea will have to be abandoned.

It is likely, however, that the Branch will take some action at a future meeting favoring some arrangement to be devised for a gathering of the Pacific Coast members at this exposition. Mr. E. G. Allen has resigned from the executive committee on account of his leaving Seattle permanently. Mr. W. S. Hoskins was elected to take his place.

The Institute paper, "On the Substitution of the Electric Motor for the Steam Locomotive" was read by different members, and discussed by Messrs. Hoskins, Moore, Magnusson, Whipple, Fairbanks, Harisberger, Read, and Wheeler.

The executive committee has outlined the following program for the balance of the year 1907:

April: "Telegraphone," by H. B. O'Reily. "Electrolytic Corrosion of Iron and Steel in Concrete," by W. S. Hoskins

May: "Hawley Pumping Plant," by Geo. H. Moore and F. G. Simpson.

June: Trip (annual) to Eastern Washington to view the single-phase electric railway of the Spokane and Inland Electric Road, and other installations. Also a paper by Mr. J. B. Ingersoll on the above mentioned railway system.

October: Banquet, at which the following are slated for three minutes' prepared speeches:

A. C. Babson, F. R. Bates, C. Edward Magnusson, W. S. Hoskins, Eugene Hockett, S. C. Lindsay, W. M. Price, A. E. Ransom, Homer W. Read, C. Remschel, Cyrus W. Whipple, John Harisberger.

November: Papers on subjects of their own choosing by T. S. Clark and C. H. Judson.

December: Paper on subject of his own choosing by O. N. Wiswell.

SYRACUSE UNIVERSITY

The meeting of this Branch held April 11, had an attendance of 22. Mr. H. E. Brelos led a discussion on the paper on "Alternating-Current Electrolysis," and Mr. H. V. Brown that on the paper "Electrolytic Corrosion of Iron and Steel in Concrete." A committee of this Branch arranged a visit to the Schenectady works of the General Electric Company, and of the American Locomotive Company, for March 26 and 27. A party of thirty made this trip.

At the next meeting, April 18, with an attendance of 16, the paper presented was on "Switchboard Construction" by Mr. Dresser of the Syracuse Lighting Company. Mr. Dresser spoke of the changes in switchboard construction in the last ten or fifteen years, and of the increased attention now paid to proper design of switchboards.

TORONTO

This Branch held a meeting March 18, at the Engineers' Club, with an attendance of 14, at which the minutes of the previous meeting were adopted as read. Mr. Robert J. Clarke gave an address on American Hydroelectric Power Development," illustrated with dissolving views. The address was most interesting and instructive, and the lecturer was tendered a hearty vote of thanks.

At the meeting of April 12, attendance 20, Mr. K. L. Aitken read Mr. P. M. Lincoln's paper on "Motor-Generators versus Synchronous Converters." The discussion on this paper was very animated, and was taken part in by Messrs. Ashworth, Bucke, Cornish, Black, Peaslee, Boyd, Richards, Aitken, Mitchell, and Smallpiece.

WASHINGTON UNIVERSITY

This Branch held a meeting February 27, with an attendance of 10. A very interesting paper on "A glimpse of Telephone Engineering" was delivered by Mr. J. F. Bratney.

WISCONSIN

The February meeting of this Branch, at the engineering building, University of Wisconsin, F. M. Conle presiding, brought out an attendance of 175. The meeting was addressed by Professor Daniel W. Mead, consulting hydraulic engineer, on "Water Power Developments in General, with Special Reference to Wisconsin."

The meeting of April 4, of this Branch, had an attendance of 40. After a brief discussion regarding the adoption of the proposed amendments to the Constitution, there was an original discussion of the "Development of Variable-Speed Motors," by J. P. Mallett, chief engineer of the Northern Electric Company. Also a review of papers on "Alternating-Current Electrolysis. by" O. H. Gaarden and "Electrolytic Corrosion of Iron and Steel in Concrete" by F. M. Blackburn.

WORCESTER POLYTECHNIC INSTITUTE

The regular meeting of the Branch was held Monday evening, March 25, 1907, in the electric engineering lecture room, Salisbury laboratories. Dr. George R. Olshausen, of Cornell University, addressed the meeting on the subject "The Power Plant of the Omaha and Council Bluffs Street Railway Co." Dr. Olshausen had been directly interested in the design of this station and was therefore in a position to give a very interesting lecture, which he did. The speaker brought a complete set of lantern-slides with him. These showed the general layout of the plant with many of the details. The method of handling coal and ashes was of special interest. Dr. Olshausen also gave some data on the operating costs of the station. The Branch wishes to express its gratitude to the speaker for his very interesting lecture.

Minutes of Meeting of the Institute

Meeting of the American Institute of Electrical Engineers, held in the Auditorium of the Engineers' Building, 33 West Thirty-ninth street, New York, Friday, March 29, 1907. President Sheldon called the meeting to order at 8:20 o'clock, P.M.

The Secretary announced that at the meeting of the Board of Directors held during the afternoon there were 139 Associates elected as follows:

AITKEN, WILLIAM, Telephone Engineer, British Insulated and Helsby Ltd.; res., Beechcliff, Sandon Prom. Egremont, Cheshire, England.

ANDERSON, JOHN VICTOR, Salesman, Westinghouse Electric and Mfg. Co.; res., 214 So. West Temple St., Salt Lake City, Utah.

APPLETON, HENRY WILLIAM, Master Mechanic, Passaic Print Works; res., 335 Lafayette Ave., Passaic, N. J.

ARIZPE, JESUS DE VALLE, Apprentice, Westinghouse Electric and Mfg. Co., Pittsburg; res., 411 McNair St., Wilkinsburg, Pa.

ATKINS, DAVID F., Inspector, Mechanical and Electrical Engineer, Superv. Architects Office, U. S. Treasury Department, Federal Bldg., Omaha, Neb

AUTH, CHARLES, Secretary and Manager, DeVean Telephone Mfg. Co.; res., 893 Decatur St., Brooklyn, N. Y.

BAINS, THOMAS MELLOR, JR., Engineer and Electrician, Rosebush Mining and Leasing Co., Goldfield, Nev.

BAKER, FRANK J., Vice-President, North Shore Electric Co., 134 Washington St., Chicago, Ill.

BAKER, HAROLD PETERS, Student, Massachusetts Institute of Technology, Boston, Mass.; res., White Haven, Pa.

BEATTIE, MARK BREWER, Electrical Engineer, 305 Commercial Bldg., Louisville, Ky.

BERRY, WILLIAM JOHNSTON, Instructor in Mathematics, Polytechnic Institute of Brooklyn; res., 1937 83d St., Brooklyn, N. Y.

BASCH, DAVID, Switchboard Engineer, General Electric Co., Schenectady, N. Y.

BEACH, HOWARD LINDSLEY, Designing Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; res., 735 Wallace Ave., Wilkinsburg, Pa.

BRISCOE, HERBERT WITHINGTON, Salesman, Ft. Wayne Electric Works, 325 Lincoln Trust Bldg., St. Louis, Mo.

BROWN, GEORGE WILLIAM, Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

BROWN, HAROLD SLATER, Agent, Canadian General Electric Co., 14 King St., E. Toronto, Ont.

CARTER, GEORGE WILLIAM, Engineering Department, Stanley G. I. Electric Mfg. Co.; res., 24 Henry Ave., Pittsfield, Mass.

CHURCHWARD, ERNEST CALERIDGE, General Manager and Engineer, Scottish Central Electric Power Co. and Lothian Electric Power Co., 34 North Bridge St., Edinburgh, Scotland.

CLARK, ROBERT J., Assistant to Comptroller, Toronto Railway Co.; res., 104 Avenue Road, Toronto, Ont.

CLAYTON, WILLIAM, Engineer, General Electric Co.; res., 631 Western Ave., West Lynn, Mass.

COLLETT, CHARLES OTTO, Instructor, Electrical Engineering, University of Missouri; res., 708 Maryland Place, Columbia, Mo.

CRAFT, WARREN MOORE, Telephone Engineer, American Telephone and Telegraph Co., 15 Dey St., New York City; res., Cranford, N. J.

CRANDALL, HERBERT NILES, Superintendent and Assistant Secretary, Baker Light and Power Co., Baker City, Oregon.

CRAWLEY, MANSFIELD CALVIN, Electrician Union Oil Co. of California, Orcutt, Cal.

DAVENPORT, URIAH HARROLD, Adjunct Professor, University of Georgia, Athens, Ga.

DAVIDSON, JOHN CHALMER, P. N. Y. & L. I. R.R., 10 Bridge St., New York; res., 31 Sidney Place, Brooklyn, N. Y.

DAVIS, ERNEST, Draftsman, Sargent & Lundy; res., 405 North Central Ave., Chicago, Ill.

DELACEY, GEORGE W., Supervising Draughtsman, Western Electric Co., E. 72d St., New York City; res., 927 Grant Ave., Bronx, New York City.

DELAFIELD, EUGENE LIVINGSTON, Salesman and Estimator, W. E. Quimby Inc.; 44 E. 23d St., New York City; res., 13 Gardner Pl., Montclair, N. J.

DICKERSON, RAYMOND, Draughtsman, New York Edison Co., New York City; res., 158 S. Elliot Pl., Brooklyn, N. Y.

DINGLE, HOWARD, Sales Department, Crocker-Wheeler Co., res.; 37 Park Ave., East Orange, N. J.

DUER, JOHN V. B., Inspector, Electrical Superintendent's Office, L. I. R.R. Co., Hempstead, L. I.

FAULDER, ALFRED JOSEPH, Chief Clerk, Engineering Department, New York and New Jersey Telephone Co.; 15 Dey St., New York City.

FOOTE, HORACE BURT, Electrical Engineer, General Electric Co., Schenectady, N. Y.

FOSTER, MORTIMER BRISTOL, Secretary and Treasurer, M. B. Foster Electric Co., 949 Broadway, New York City; res., Sound Beach, Conn.

FOWLER, CLARENCE PARKES, Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; res., 3 Cope Apartment, Wilkinsburg, Pa.

FRANCIS, JOSEPH SIDNEY, Engineer, Bell Telephone Co. of Philadelphia, N. E. cor. 11th and Filbert Sts., Philadelphia, Pa.

FRENELL, PER, Electrical Engineer, Elektriska Pronfingsanstalten, Dalagatan 30 IV, Stockholm, Sweden.

FULLERTON, HUGH LEE, Assistant to Electrical Engineer, Allegheny County Light Co.; res., 5808 Margaretta St., Pittsburg, Pa.

GAPEN, JOTHAM CLARK, Electrical Inspector, North Shore Electric Co., 114 Oak Park Ave.; res., 310 South Boulevard, Oak Park, Ill.

GANGL, FRANCIS, Draftsman, General Electric Co.; res., 26 Glenwood Boulevard, Schenectady, N. Y.

GARDINER, FREDERICK W., Principal Assistant Engineer, Interborough Rapid Transit Co., 32 Park Place, New York City.

GAYLORD, JAMES MASON, Student, Massachusetts Institute of Technology; res., 4 Kearsarge Ave., Roxbury, Mass.

GOODING, HENRY L., Electrician in charge Department of Ordnance, Brooklyn Navy Yard, N. Y.

GORSUCH, WILLIAM SCHROFIELD, Assistant Electrical Engineer, N. Y. C. & H. R. R.R. Co., New York City; res., 55 S. 3d Ave., Mt. Vernon, N. Y.

GUILD, JOSEPHUS CONN, Chief Engineer, Chattanooga and Tennessee River Power Co., Chattanooga, Tenn.

HADDOCK, MORTON WEBSTER, Superintendent of Maintenance, New England Telephone and Telegraph Co., 119 Milk St., Boston; res., Brookline, Mass.

Hazard, Isaac Peace, Assistant to Chief Engineer, Cincinnati Traction Co., 1312 Traction Bldg., Cincinnati, O.

Heavens, Fred John, Purchasing Agent, Pittsburg and Allegheny Telephone Co., Pittsburg; res., 306 Jackson St., Allegheny, Pa.

Helweg-Fahnoi, Hans Frederik Inspector, Westinghouse Electric and Mfg. Co.; res., 102 Plane St., Newark, N. J.

Herman, Joseph W., Inspector, Switchboard Drafting Department, General Electric Co.; res., 144 Barrett St., Schenectady, N. Y.

Huntington, Arthur, President Cascade Milling Co., 405 W. 8th St., Sioux Falls, S. D.

Huper, Carl, Electrical Draftsman, with W. J. Gray; res., 808 4th Ave., S., Minneapolis, Minn.

Hurdell, Victor Hollister, Salesman, Westinghouse Electric and Mfg. Co., 716 Bd. of Trade Building, Boston, Mass.

Hurlbatt, Douglas Gray, Assistant Engineer in Plant Department, British Westinghouse Co., Trafford Park, Manchester; res., Bickley, Kent, Eng.

Hyland, John Francis, Foreman of Maintenance, New England Telephone and Telegraph Co., Boston; res., 7 Pembroke St., Medford, Mass.

Joseph, Abraham Pinto, Switchboard Engineer, General Electric Co.; res., 128 Nott Terrace, Schenectady, N. Y.

Keal, Joseph, Jr., Draughtsman, Industrial Gas Co..Flatiron Bldg., New York City; res., 968 Madison St., Brooklyn, N. Y.

Keiser, David L., Erecting Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.; res., Rushville, Ind.

Keyes, Frederick A., Sales Engineer, American Steel and Wire Co., 24 State St., New York City; res., 393 North Broad St., Westfield, N. J.

Kirkpatrick, William Burns, Engineer and Salesman, General Electric Co., 44 Broad St., New York City; res., 1524 E. 19th St., Brooklyn, N. Y.

Kittelberger, John B., Chief of Maintenance, Central District and Printing Telegraph Co.; res., 416 7th Ave., Pittsburg, Pa.

Koester, Frank, Designing Engineer, J. G. White and Co.; res., 213 W. 81st St., New York City.

Kuhn, Lewis O., Assistant Engineer, American Tobacco Co., 111 5th Ave.; res., 238 W. 73d St., New York City.

Lambert, Carl Fred, Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; res., 420 Rebecca Ave. Wilkinsburg, Pa.

Lathrop, Leigh Hunt, Foreman, Electrical Testing Bureau, Milwaukee Electric Railway and Light Co.; res., 1414 Grand Ave., Milwaukee, Wis.

Laudenberger, Ernest C., Student Apprentice, General Electric Co.; res., 60 Commercial St., West Lynn, Mass.

Lehder, Walter Max, General Electric Co.; res., 127 Glenwood Boulevard, Schenectady, N. Y.

Lide, Martin James, Consulting Electrical Engineer, Birmingham, Ala.

Liebermann, Paul B., Assistant Electrical Engineer, Sprague Electric Co., Bloomfield; res., 273 N. 20th St., East Orange, N. J.

Longbotham, Frank, Student, Brooklyn Polytechnic Institute; res., 322 Carlton Ave., Brooklyn, N. Y.

Lunn, Ernest, Superintendent of Storage Batteries, Chicago Edison Co., 139 Adams St., Chicago, Ill.

Manley, Robert E., General Manager, Hanover Light Heat and Power Co., Hanover and McSherrystown Street Railway Co., Hanover, Pa.

Martin, George W., 245 Carroll St., Brooklyn, N. Y.

Mason, Edward Jarvis King, Westinghouse, Church, Kerr and Co., 10 Bridge St., New York City; res., 370 Park Place, Brooklyn, N. Y.

Mason, Walter Lloyd, Salesman, Westinghouse Electric and Mfg. Co., Land Title Bldg.; res., 1527 Green St., Philadelphia, Pa.

Mazzolani, Guilio, Electrical Engineer Societa della tramori e ferrsvie Electriche d Roma, L 7 Via Firenze, Rome, Italy.

McBride, Albert Hillier, Assistant Engineer, Hydro-Electric Power Commission of Ontario, 25 Toronto St.; res., 105 Bond St., Toronto, Ont.

McCarthy-Jones, Christopher Howel, Engineer on Staff, British Thomson-Houston Co., Rugby, England.

McElhany, Alva Roy, Foreman, Mexican Light and Power Co., Eliseo 34, Vivienda No. 6, Mexico D. F., Mex.

McLaren, John Harold, Assistant Chief Engineer, Cincinnati, Newport and Covington Light and Traction Co., Newport, Ky.

McRae, Frank George, Electrical Inspector, Hudson River Electric Power Co., 192 3d St., Albany, N. Y.

Merrick, Frank Anderson, Manager of Works, Canadian Westinghouse Co. Ltd., Hamilton, Ont.

Meyer, Eugene Daniel, Consulting Engineer, Falkenau Electrical Construction Co., 201 Stock Exchange Building; res., 346 Oakwood Boulevard, Chicago, Ill.

Minami, Hajime, Draftsman, Westinghouse, Church, Kerr and Co.; 10 Bridge St.; res., 2 W. 131st St., New York City.

Morehead, Roy Archibald, Engineer, The Pacific Telephone and Telegraph Co.; res., 622 So. Hill St., Los Angeles, Cal.

Mousselet, Marcel Eugene, Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; res., 417 Biddle Ave., Wilkinsburg, Pa.

Nachod, Carl Pivany, President, United States Engineering Co., 633 Bourse Bldg.; res., 5384 Chew St., Philadelphia, Pa.

Nathan, Wilfred McDowell, Electrician, United States Gypsum Co., Oakfield, N. Y.

Newman, Leroy L., Inspector, Pennsylvania Railroad Co., 314 Delaware Ave., N. E., Washington, D. C.

Nowlan, Brete Cassius, Installation Department, Western Electric Co., Chicago, Ill.; res., Havelock, Ia

Pearson, Albert L., Assistant, Lockwood, Greene and Co., 93 Federal St., Boston; res., 10 Dresden Circle, West Somerville, Mass.

Peddrick, Charles Henry, Jr., Manager, Light and Power Department, Hudson River Electric Power Co., Glens Falls, N. Y.

Phinney, Robert Morris, Draughtsman, Northwestern Construction Co. Boone, Ia.

Pierson, Henry, Electrical Engineer, British Westinghouse Electric and Mfg. Co.; Trafford Park; res., 26 Park Road, Stretford, Manchester, Eng.

Poole, William John, Engineer and Salesman, British Westinghouse Electric and Mfg. Co. Ltd.; res., 31 Falkland Mansions, Hyndland, Glasgow, Scotland.

Poppleton, Ralph Riggs, Sales Engineer, Pacific Electric Co., 94 First St., Portland, Oregon.

Powell, Ivan Elno, Engineer, Rochester Railway and Light Co., 120 Broadway, Rochester, N. Y.

Pratt, Richard Henry, Chief Electrician, N. P. Pratt Laboratory, Atlanta, Ga.

Pringle, David Rhett, Superintendent, Thomasville Electric Light Plant, Thomasville, Ga.

Raymond, Howard Monroe, Dean, Professor Experimental Physics, Armour Institute of Technology, Chicago, Ill.

Remington, George Ward, Engineer Railway Department, General Electric Co., Schenectady, N. Y.

Ribot, Antonio, Tester General Electric Co.; res., 131 Church St., Schenectady, N. Y.

Rice, Philip Bernard, Assistant in Office of Mechanical Engineer, Pennsylvania Railroad Co., Altoona, Pa.

Rich, Edward Benjamin, Field Accountant on Coast Analysis, Northwestern Construction Co., Boone, Ia.

Riddile, John Scott, Engineer, with Ralph D. Mershon, 60 Wall St.; res., 102 W. 84th St., New York City.

Ropp, Otho Clarence, Tester, General Electric Co.; res., 103 Barrett St., Schenectady, N. Y.

Ryan, William Thomas, Instructor in Electrical Engineering, University of Minnesota; res., 1406 7th St., S. E., Minneapolis, Minn.

Samuels, Maurice M., Engineer, General Electric Co., Schenectady, N. Y.

Scholes, Daniel Ransom, Chief Engineer, Aermotor Co., 12th and Rockwell Sts., Chicago, Ill.

Sclater, Robertson Hoskins, Electrical Draftsman, Newport News Shipbuilding and Dry Dock Co., Hampton, Va.

Scott, George Walker, Electrical Engineer, Allis-Chalmers Co., The Bullock Electric Mfg. Co., Norwood, O.

Seaman, John H., Chief Engineer, Consumers Electric Co.; res., 2618 Coliseum St., New Orleans, La.

Sheridan, Martin Philip, Chief Electrician Peregrina Mining and Milling Co., Peregrina, Guanajuato; res., Cadena 19, Mexico D: F., Mex.

Simpson, George W., Salesman, Westinghouse Electric and Mfg. Co.; res., 22 N. 59th St., Philadelphia, Pa.

Smart, John Cowie, Superintendent of Transmission Lines, Shawinigan Water and Power Co., Joliette, P. Q. Canada.

Smith, Algy J., Electrician in Charge Naval Proving Ground, Indian Head, Md.

Smith, Walter Charles, General Electric Co.; res., 1009 Union St., Schenectady, N. Y.

Smith, William McAllister, Telephone Engineer, Western Electric Co.; res., 301 E. 68th St., New York City.

Spencer, Elbert Roy, Assistant Editor, *Electric Journal*, Pittsburg, Pa.

Stieler, Frederick Carl, Engineering Department, Westinghouse Electric and Mfg. Co.; res., 417 Center St., Wilkinsburg, Pa.

Stewart, Richard Glyde, General Foreman Memphis Street Railway Co., 586 Lauderdale St., Memphis, Tenn.

Symes, Harry, Superintendent, Electrical Development Co., Niagara Falls, N. Y.

Taussig, William S., Sales Engineer, Western Electric Co.; res., 36 W. 85th St., New York City.

Thayer, Harry Bates, Vice President Western Electric Co., 463 West St., New York City.

Thibodeaux, Ernest Augustus, Superintendent, Municipal Power Plant, Donaldsonville, La.

Tomlinson, L. C., Installer, Automatic Electric Co., Oakland, Cal.

Trafford, Bernard Walton, General Manager, Chesapeake and Potomac Telephone Co., 722 12th St. N. W., Washington, D. C.

Tyler, Alva Warren, Designing Engineer, United States Gypsum Co., Oafikeld, N. Y.

Urquhart, Robert Frazier, Assistant Installing Engineer, Northern California Power Co., Manton, Cal.

Vance, Claude Edward, Assistant Engineer, British Electric Traction Co., Ltd., Donnington House, Norfolk St., London, W. C., England.

Van Weelden, Harold C., Sales Department, General Electric Co., 44 Broad St., New York City; res., 450 Willoughby Ave., Brooklyn, N. Y.

Watanabe, Noble, Engineering Apprentice Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

Wilkins, George Barnum, Student, Brooklyn Polytechnic Institute, Brooklyn; res., 3403 Beaufort St., Morris Park, L. I., N. Y.

Wiemer, Otto, Engineer, Wagner Electric Mfg. Co., St. Louis, Mo.; res., 814 Alby St., Alton, Ill.

Williams, Samuel Alfred, Electrical Contractor, S. A. Williams and Co., Jackson, Miss.

Wily, James Hunter, Private Assistant, W. S. Franklin, Lehigh University; res., 704 Dakota St., So. Bethlehem, Pa.

Winter, William George, Chief Draftsman, Emerson Electric Mfg. Co., 2030 Washington Ave.; res., 2101a Arsenal St., St. Louis, Mo.

Woltman, Ernst, Manager, Albert and J. M. Anderson Mfg. Co., 135 Broadway; res., 610 W. 113th St., New York City.

The Secretary announced further that the following Associates were transferred to the grade of Member:

Alexander Suss Langsdorf, Professor of Electrical Engineering, Washington University, St. Louis, Mo.

Leslie Lawrence Perry, Electrical Engineer with F. S. Pearson, 25 Broad St., New York City.

The Secretary announced further that at the meeting of the Board of Directors the following men were selected as the directors' nominees for the officers of the Institute to be elected on May 9, 1907.

For president, Henry Gordon Stott, New York, N. Y.

For vice-presidents, Louis A. Ferguson, Chicago, Ill.; W. C. L. Eglin, Philadelphia, Pa.; J. G. White, New York, N. Y.

For managers, Percy H. Thomas, New York, N. Y.; B. G. Lamme, Pittsburg, Pa.; Harold W. Buck, New York, N. Y.; Morgan Brooks, Urbana, Ill.

For treasurer, George A. Hamilton, New York, N. Y.

For secretary, Ralph W. Pope, New York, N. Y.

The following papers were then presented:

1. "Lightning Phenomena in Electric Circuits," by Charles P. Steinmetz.
2. "Protection against Lightning, and the Multigap Lightning-Arrester," by D. B. Rushmore and D. Dubois.
3. "New Principles in the Design of Lightning-Arresters," by E. E. F. Creighton.

The following members took part in the discussion: Messrs. Steinmetz, R. P. Jackson, Converse, McClellan, Osgood, Rushmore, Creighton, Perrine, Thomas.

Question Box

The annual "question box" of the National Electric Light Association has been printed for distribution under the editorial supervision of Mr. Paul Lupke. It will be found of special interest to operating electrical engineers. Copies may be obtained by addressing the Secretary of the Association, 29 West 39th street, New York City.

I cannot but think that the foundations of all natural knowledge were laid when the reason of man first came face to face with the facts of nature; when the savage first learned that the fingers of one hand are fewer than those of both; that it is shorter to cross a stream than to head it; that a stone stops where it is unless it be moved, and that it drops from the hand which lets it go; that light and heat come and go with the sun; that sticks burn away in a fire; that plants and animals grow and die; that if he struck his fellow savage a blow, he would make him angry, and perhaps get a blow in return; while if he offered him fruit, he would please him, and perhaps receive a fish in exchange. When men had acquired this much knowledge, the outlines, rude though they were, of mathematics, of physics, of chemistry, of biology, of moral, economical, and political science, were sketched.—Huxley, "The Scientific Spirit in Modern Thought."

Institute Meetings

May Meeting, May 21, 1907:

"Facts and Problems Relating to Electric Trunk Line Operation," by F. J. Sprague.

High-Tension Transmission Committee.

Chicago Meeting, May 24, 1907:

"Relative Merits of Three-Phase and One-Phase Transformers," by H. W. Tobey.

"Relative Advantages of One-Phase and Three-Phase Transformers," by John S. Peck.

"Forced-Oil and Forced-Water Circulation for Cooling Oil-Insulated Transformers," by C. C. Chesney.

"Enclosed Station Wiring," by F. O. Blackwell.

"Potential Stresses as Affected by Overhead Grounded Conductors," by R. P. Jackson.

Annual Convention, Niagara Falls, N. Y.

June 25-28, 1907.

Niagara Falls Convention Local Committee, 1907.

Philip P. Barton, Chairman;
E. C. Acheson, F. B. H Paine.
H. B. Alverson. W. N Ryerson.

Titles of Papers*

"New Principles in the Design of Lightning-Arresters," by E. E. F. Creighton.

"Some Power Transmission Economics," by F. G. Baum.

"Notes on Transformer Testing," by H. W. Tobey.

"One-Phase, High-Tension Power Transmission," by E. J. Young.

"Fractional Pitch Windings for Induction Motors and Alternators," by C. A. Adams.

"Short-Circuit Currents of Alternators," by C. P. Steinmetz.

"Attitude of Technical Schools toward the Profession of Electrical Engineering," by H. H. Norris.

"The Concentric Method of Teaching Electrical Engineering," by Valdemir Karapetoff.

"Track-circuit Signaling on Electrified roads" by L. F. Howard.

"Method of Measurement in Lightning-Arresters or Standardization Rules," by E. E. F. Creighton.

"Practical Testing of Commercial Lightning-Arresters, by Percy H. Thomas.

"Engineering Specifications," by C. W. Ricker.

"Vector Diagrams of Single-Phase Commutating Motor," by W. I. Slichter.

"The Application of Oil Switches in Power Transmission Work," by D. B. Rushmore.

"Inductive Disturbances in Telephone Lines," by Louis Cohen.

"Some Aspects of Parallel Operation," by B. O. Behrend, O. B. Field, and J. M. Patitz.

"Zigzag Leakage of Induction Motors," by R. E. Hellmund.

"Deflocculated Graphite," by E. G. Acheson.

"Regeneration of Power from Electric Railway Motors," by William Cooper.

"Switchboard Practice for Voltages of 60,000 and Upward," by S. Q. Hayes.

"Power-Factor, Alternating-Current Inductive Capacity, Chemical, and Other Tests of Rubber-Covered Wires of Different Manufacturers," by Henry W. Fisher.

"Interaction of Synchronous Machines," by Morgan Brooks.

Topical Discussions:

1. "Single-Phase versus Multiphase Generators for Alternating-Current Roads."
2. "Standardizing the Frequency for Alternating-Current Roads,"
A. H. Armstrong, railway engineering department., General Electric Company, Schenectady, N. Y.; and N. W. Storer, Westinghouse Electric and Manufacturing Company, Pittsburg, Pa.

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* This list may be modified later.

Under the Auspices of the High-Tension Transmission Committee, Wednesday, June 26, 1907.

"Extra Insulation of End-Turns of Transformer Windings as a Substitute for Lightning-Arrester Choke-Coils," by S. M. Kintner.

"Extra Insulation of End-Turns of Transformer Windings as a Substitute for Lightning-Arrester Choke-Coils," by Walter S. Moody.

"Transmission Line Towers and Economical Spans," by D. R. Scholes.

"Lightning-Rods and Grounded Cables as a means of Protecting Transmission Lines against Lightning," by Norman S. Rowe.

"The Transmission Plant of the Niagara, Lockport and Ontario Power Company," by Ralph D. Mershon.

"Location of Broken Insulators and Other Transmission Line Trouble ," by L. C. Nicholson

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High-Tension Transmission Committee

High-Tension Transmission Meeting at New York, March 22, 1907.

A special meeting of the Institute under the direction of Mr. Ralph D. Mershon, chairman of the High-Tension Transmission Committee, was held in the Auditorium of the Engineers' Building, New York, Friday March 22, 1907. The meeting was a large one, and the discussion spirited and interesting. The following "Introductions to Discussions" were presented:

1. "Motor-Generators versus Synchronous Converters, with Special Reference to Operation on Long-Distance Transmission Lines," by Paul M. Lincoln.
2. "The Practicability of Large Generators Wound for 20,000 Volts," by B. A. Behrend.

The following members took part in the discussion: Messrs. Behrend, Skinner Murray, Armstrong, Waters, Stott, Mershon, Stone, Thomas, Torchio, Henshaw, Scott, Lincoln, Berg, Blackwell, Corson, Kelsch, Jackson, Pratt, Schuler, Shipman, Coldwell, Floy, Foster, Gifford, Osgood, Parker, Parshall, Pearson, Rowe, Schwartz, Walker, Whitehead, Babcock, Burch, Semenza.

High-Tension Transmission Meeting at Chicago, May 24, 1907.

A special meeting of the Institute under the auspices of the Chicago Branch and the High-Tension Transmission Committee, will be held in the Auditorium Hotel, Michigan Avenue, Chicago, on Friday, May 24, 1907. There will be two sessions, possibly three. The first session will be from 9 a.m. to 1 p.m.; the second, from 2:30 p.m. to 5 p.m. If the papers and discussions are not finished at 5 p.m., there will be an evening session beginning at 8 p.m.

The following "Introductions to Discussion" will be presented at the Chicago meeting:

1. "Relative Merits of Three-Phase and One-Phase Transformers," by H. W. Tobey.
2. "Relative Advantages of One- Phase and Three-Phase Transformers," by John S. Peck.
3. "Forced-Oil and Forced-Water Circulation for Cooling Oil-Insulated Transformers," by C. C. Chesney.
4. "Enclosed Station Wiring," by F. O. Blackwell.
5. "Potential Stresses as Affected by Overhead Grounded Conductors," by R. P. Jackson.

Professor P. B. Woodworth, of the Lewis Institute of Chicago, is chairman of the Chicago Branch; Mr. H. R. King of the Western Electric Company, is secretary. Messrs Woodworth and King are cordially and actively cooperating with Mr. Mershon and the executive offices of the Institute in the endeavor to assure a large and successful meeting, as large and as successful as that held under the auspices of the

High-Tension Transmission Committee, in New York, on March 22, 1907. At the New York meeting, thirty-six members took part in the discussion, the stenographic transcript of the discussion covering 121 pages of legal-cap paper.

The Secretary requests all members, having experience in matter relative to the electrical transmission of energy at high voltages and who are therefore qualified to discuss the points brought out in these Introductions, kindly to assist Mr. Mershon's committee in this important work by contributing to the discussions, either verbally at the meeting, or, if this is not convenient, by written contributions. If the contributions are to be verbal, please notify Mr. Pope by letter; if the contributions are to be written, they should be sent to Mr. Mershon at his office, 60 Wall Street, New York, mailing them so that they will reach him on or before May 20, 1907.

High-Tension Transmission Meeting, at Niagara Falls, N. Y., June 26, 1907.

By special arrangement with Mr. H. G. Stott, chairman of the Committee on Papers, one entire day—June 26—of the Annual Convention at Niagara Falls, N. Y. during the week beginning June 24, 1907, will be devoted to the reading and discussing of the following "Introductions to Discussion"

"Extra Insulation of End-Turns of Transformer Windings as a Substitute for Lightning-Arrester Choke-Coils," by S. M. Kintner.

"Extra Insulation of End-Turns of Transformer Windings as a Substitute for Lightning Arrester Choke-Coils," by Walter S. Moody.

"Transmission Line Towers and Economical Spans," by D. R. Scholes.

"Lightning-Rods and Grounded Cables as a means of Protecting Transmission Lines against Lightning," by Norman W. Rowe.

"The Transmission Plant of the Niagara, Lockport, and Ontario Power Company," by Ralph D. Mershon.

"Location of Broken Insulators and Other Transmission-Line Troubles," by L. C. Nicholson.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting.

Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before May 21, 1907.

6009 Wm. Beneze, Baltimore, Md.
6010 Einar Brofos, Chicago, Ill.
6011 W. B. T. Belt, Omaha, Neb.
6012 E. W. Crane, Orizaba, Mexico.
6013 F. A. Chamberlain, Philadelphia.
6014 C. E. Clewell, Bethlehem, Pa.
6015 H. W. Eells, New York City.
6016 Edward Gottlieb, Boston, Mass.
6017 J. D. Gaboury, Gadsden, Ala.
6018 H. R. Gabay, New York City.
6019 H. U. Hart, Hamilton, Ont.
6020 J. F. Howard, Jersey Shore, Pa.
6021 A. L. Jones, Schenectady, N. Y.
6022 Dirk Kos, Niagara Falls, N. Y.
6023 R. Meriweather, Louisville, Ky.
6024 Barry McNutt, Bethlehem, Pa.
6025 H. B. Morrell, Brooklyn, N. Y.
6026 H. B. Oakman, New York City.
6027 P. D. Parsons, Philadelphia, Pa.
6028 C. L. Parrington, Dunedin, N. Z.
6029 Otto Pruessman, Chicago, Ill.
6030 G. C. Thornton, Birmingham, Ala.
6031 Wm. G. Wall, Indianapolis, Ind.
6032 W. A. Barrett, Missoula, Mont.
6033 V. R. N. Cowsik, Mysore, India.
6034 H. B. Dorman, Toledo, O.
6035 W. G. Fox, New York City.
6036 L. J. Flint, Chicago, Ill.
6037 C. R. Gill, Sacramento, Cal.
6038 C. B. Gilson, Wilkinsburg, Pa.
6039 J. H. Hunt, St. Louis, Mo.
6040 A. St. J. Hill, Norwalk, Conn.
6041 A. W. Helmholtz, Chicago, Ill.
6042 W. Hess, Bale Munchenstein, Switzerland.
6043 S. M. McFedries, Chicago, Ill.
6044 R. Roth, Mexico City, Mex.

6045 L. P. Russell, Boston, Mass.
6046 M. S. Sloan, Birmingham, Ala.
6047 F. R. Stone, Bakersfield, Cal.
6048 H. R. Stevens, Seattle, Wash.
6049 J. Schuermann, Wilkesbarre, Pa.
6050 J. E. Sweeney, Pine Beach, Va.
6051 C. G. Thockmorton, Omaha, Neb.
6052 D. M. Ashbridge, Philadelphia, Pa.
6053 Reginald Belfield, London, Eng.
6054 H. L. Bright, Brooklyn, N. Y.
6055 S. F. Jones, Brooklyn, N. Y.
6056 J. H. McDougal, Corvallis, Ore.
6057 F. A. Schroeder, Johnstown, Pa.
6058 L. K. Sager, New York City.
6059 Wm. McC. Sawyer, Bangor, Me.
6060 F. Koschcrak, Paris, France.
6061 L. W. Walker, North Platte, Neb.
6062 H. L. Burns, New York City.
6063 E. P. Beckwith, Garrison, N. Y.
6064 A. R. Bingham, Corinth, N. Y.
6065 L. J. Deremo, Cincinnati, O.
6066 W. A. Houghtaling, Baltimore, Md.
6067 C. Hoff, Jr., St. Paul, Minn.
6068 S. B. Jones, Schenectady, N. Y.
6069 E. Y. Sayer, New York City.
6070 H. H. Kyser, Talladega, Ala.
6071 J. H. Bailey, Kansas City, Mo.
6072 H. M. Diehl, Provo, Utah.
6073 H. M. Frantz, Chicago, Ill.
6074 P. W. Gerhardt, Schenectady, N.Y
6075 A. L. Harrington, Wilkinsburg, Pa
6076 J. H. Hessin, Pontiac, Ill.
6077 F. G. Haldy, Glenbrook, Conn.
6078 H. E. Murty, Shamokin, Pa.
6079 R. M. Newbold, Chicago, Ill.
6080 H. W. Osgood, Boston, Mass.
6081 P. D. Rapelji, Brooklyn, N. Y.
6082 H. G. Smith, Toronto, Ont.
6083 F. S. Tucker, Charlotte, N. C.
6084 H. J. Wiegand, Milwaukee, Wis.
6085 O. R. Aanes, Brookings, S. D.
6086 H. Bigelow, Norwich, Conn.
6087 H. F. Bush, Jr., Philadelphia, Pa.
6088 C. E. Carter, Madison, Wis.
6089 Jake Danner, Oak Park, Ill.
6090 J. P. Dinsmore, Chicago, Ill.
6091 C. L. Howk, Chicago, Ill.
6092 J. W. Hulbert, Jr., Auburn, N. Y.
6093 E. H. Minehardt, Gaylordsville, Conn.
6094 Taliaferro Milton, Cleveland, O.
6095 J. S. Maltman, Kankakee, Ill.
6096 W. S. Munro, Terre Haute, Ind.
6097 Wm. F. Neiman, Berkeley, Cal.
6098 E. A. R. Nowlan, Chicago, Ill.
6099 L. P. Perry, Clemmons, N. C.
6100 J. J. Rooney, New York City.
6101 H. L. Davisson, New York City.
6102 R. B. Kellogg, Hartford, Conn.
6103 W. L. Hartzell, Baltimore, Md.
6104 N. H. Black, Cambridge, Mass.
6105 Harry Goldberg, New York City.
6106 A. J. Hixon, Braintree, Mass.
6107 E. E. Ranney, Chicago, Ill.
6108 G. W. Smith, Austin, Tex.
6109 L. D. Waldron, Buffalo, N. Y.
6110 G. M. Willis, Chicago, Ill.
6111 J. L. Harrington, New York City.
6112 L. M. McBride, Denver, Colo.
6113 W. A. Redshaw, New Brunswick, N. J.
6114 G. E. Shepherd, Wilkesbarre, Pa.
6115 R. M. Tristian, Brooklyn, N. Y.
6116 W. F. Barnes, Kansas City, Mo.
6117 C. D. Bidwell, Chicago, Ill.
6118 H. P. Clarke, New York City.
6119 T. A. Hill, New York City.
6120 E. E. Hinrichsen, Chicago, Ill.
6121 J. M. Mahoney, Boston, Mass.
6122 R. E. Newcombe, Ithaca, N. Y.
6123 A. E. Pope, New York City.
6124 Y. Sakai, Pittsburg, Pa.
6125 D. C. Woodard, Schenectady, N. Y.
6126 J. Zimmerman, Newark, N. J.
6127 Austin Burt, Waterloo, Ia.
6128 D. F. Bernhardt, New Brighton, N. Y.
6129 W. E. Barrows, Jr., Chicago, Ill.
6130 Earl B. Hoff, Toledo, O.
6131 E. E. Cary, New York City.
6132 H. W. DeVed, New Rochelle, N. Y.
6133 Wm. A. Hill, Toledo, O.
6134 J. C. Langdell, Albany, N. Y.
6135 Allan Ramsey, St. Louis, Mo.
6136 E. E. Winters, Brooklyn, N. Y.
6137 W. J. Bishop, Milwaukee, Wis.
6138 E. J. Bartlett, Hartford, Conn.
6139 J. J. Caufield, Schenectady, N. Y.
6140 A. L. Duckett, Asheville, N. C.
6141 E. H. Hoppenstedt, Brooklyn, N. Y.
6142 H. H. Hunt, Savannah, Ga.
6143 W. H. Hoag, New Orleans, La.
6144 Wm. S. Jones, Philadelphia, Pa.

6145 Wm. Roberts, Akron, O.
6146 John Stack, Chicago, Ill.
6147 J. E. Woodwell, Washington, D.C.
6148 Wm. Bradford, Lincoln, Neb.
6149 Wm. B. Beals, Baltimore, Md.
6150 T. A. Banning, Jr., Chicago, Ill.
6151 C. E. Fairbanks, Newark, N. J.
6152 W. W. Grant, New York City.
6153 R. M. Henderson, Chicago, Ill.
6154 P. L. McCain, Schenectady, N. Y.
6155 A. D. Rickenbacher, Washington, D. C.
6156 M. Silverman, Olean, N. Y.
6157 J. J. Woolfenden, Detroit, Mich.
6158 G. L. Yates, Mt. Vernon, N. Y.
6159 C. C. Brown, Philadelphia, Pa.
6160 J. N. Downey, Camden, N. J.
6161 N. E. Funk, Atlanta, Ga.
6162 F. H. Foster, Flushing, L. I., N. Y.
6163 H. P. James, Bridgeport, Conn.
6164 R. Josephi, New York City.
6165 C. D. Little, Montclair, N. J.
6166 O. D. McClure, Ishpeming, Mich.
6167 R. F. Mather, Lac du Bonnet, Man.
6168 R. Rankin, Sao Paulo, Brazil.
6169 W. M. Skiff, Cleveland, O.
6170 H. C. Houck, Cincinnati, O.
6171 A. E. Ranney, New York City.
6172 A. G. Ellis, London, Eng.
6173 H. LeR. Hope, Chicago, Ill.
6174 H. H. Hoy, Brookings, S. D.
6175 J. Sibbald, Gloversville, N. Y.
6176 J. B. Tingley, Madison, Wis.
6177 Wm. F. Yeager, Chester, Pa.
6178 F. E. Bullock, Baltimore, Md.
6179 F. E. Chappelow, St. Louis, Mo.
6180 E. E. Loomis, Schenectady, N. Y.
6181 H. A. Steen, Edgewood Park, Pa.
6182 J. E. Webster, Pittsburg, Pa.
6183 J. M. Weed, Pittsburg, Pa.
6184 A. T. Beazley, Schenectady, N. Y.
6185 Wm. N. Miller, Detroit, Mich.
6186 W. Arnstein, San Francisco, Cal.
6187 A. A. Atkinson, Athens, O.
6188 E. Corrigan, Baltimore, Md.
6189 H. C. Dieher, Tamaqua, Pa.
6190 R. A. Gulick, Visalia, Cal.
6191 E. H. Lane, Brooklyn, N. Y.
6192 J. Muirhead, Rugby, England.
6193 O. M. Roberts, Orangeburg, S. C.
6194 C. D. Richardson, Cambridge, Mas
6195 H. N. Stillman, Philadelphia, Pa.
6196 J. M. Smith, E. Orange, N. J.
6197 F. M. Sturgess, Chicago, Ill.
6198 C. H. Taylor, So. Wellfleet, Mass.
6199 C. E. Watrous, New York City.
6200 A. Allison, Dunedin, N. Z.
6201 J. Adams, Los Angeles, Cal.
6202 C. H. Christensen, Missoula, Mont.
6203 N. B. Davis, Wilkinsburg, Pa.
6204 J. J. Dorney, St. Louis, Mo.
6205 F. V. Greene, Buffalo, N. Y.
6206 Selby Haar, Schenectady, N. Y.
6207 R. T. Knaur, Vienna, Austria.
6208 J. C. Zengerle, Brooklyn, N. Y.
6209 G. W. Meadows, Lambert Pt., Va.
6110 O. L. Morgenstern, Brooklyn, N.Y.
6211 Harold Plumley, Chicago, Ill.
6212 A. B. Reynders, Pittsburg, Pa.
6213 D. Sadler, Great Falls, S. C.
6214 Clarence E. Watts, Windber, Pa.
6215 R. Wesselhoeft, Shanghai, China.
6216 J. A. Beckstrom, St. Paul, Minn.
6217 F. W. Gay, Ampere, N. J.
6218 L. E. Hamilton, Elyria, O.
6219 J. A. Nornam, Terre Haute, Ind.
6220 W. H. Seaver, San Francisco, Cal.
6221 W. H. Tolman, New York City.
6222 L. F. Woodhead, Albuquerque, N. M.
6223 T. W. Atkinson, Baton Rouge, La.
6224 E. D. Ellis, Plant City, Fla.
6225 R. P. Evans, Jr., Wilkinsburg, Pa.
6226 C. D. Backus, Washington, D. C.
6227 Henry G. Blakeney, Dallas, Tex.
6228 Allan Chapman, Buffalo, N. Y.
6229 G. L. Crosby, Cleveland, O.
6230 T. E. Fox, Greenwich, Conn.
6231 O. L. Harrison, Chicago, Ill.
6232 E. S. Harris, Swarthmore, Pa.
6233 D. J. Kerr, Canton, N. C.
6234 F. MacLehose, New York City.
6235 H. D. Bailey, New York City.
6236 L. R. Morshead, Liverpool, Eng.
6237 W. B. Purse, Savannah, Ga.
6238 T. Pinckney, Asheville, N. C.
6239 A. H. Potter, Minneapolis, Minn.
6240 L. A. Pease, Highwood, Ill.
6241 C. V. Rapelji, Brooklyn, N. Y.
6242 P. G. Robinson, St. Paul, Minn.
6243 T. G. Sexas, New York City.
6244 A. E. Silver, Raleigh, N. C.
6245 B. R. Shover, Gray, Ind.
6246 E. F. Schaefer, New York City.
6247 W. Van Riper, Bronx, N. Y.
6248 P. A. Westburg, Chicago, Ill.

6249 L. G. Yochum, Brooklyn, N. Y.
6250 W. A. Carter, Denver, Colo.
6251 M. C. Henderson, Dunedin, N. Z.
6252 J. P. Hansen, Joliet, Ill.
6253 W. H. Leonard, Toledo, O.
6254 I. N. Lewis, Ft. Monroe, Va.
6255 G. J. McElwee, Launceston, Tasmania.
6256 H. W. Matthews, Great Falls, S.C.
6257 J. H. Warder, Chicago, Ill.
6258 P. M. Brown, Turbine P. O., Ont.
6259 W. T. Bivins, San Francisco, Cal.
6260 R. C. Downing, Buffalo, N. Y.
6261 J. T. Fuller, Plant City, Fla.
6262 J. N. Gilbert, Norwich, Conn.
6263 M. D. Gould, Buffalo, N. Y.
6264 C. H. Messer, Spokane, Wash.
6265 W. McK. McClintock, St. Paul, Minn.
6266 M. L. Norris, Fort Wayne, Ind.
6267 Geo. Nixon, Spokane, Wash.
6268 A. Press. Washington, D. C.
6269 E. F. Smith, Chicago, Ill.
6270 J. H. Smeaton, Lac du Bonnet, Man.
6271 H. L. Steiner, Cleveland, O.
6272 C. E. Vawter, Jr., Blacksburg, Va.
6273 G. T. Wood, Rugby, England.
6274 S. E. Woodbury, Cambridge, Mass
6275 H. B. Zimmerman, Buffalo, N. Y.
6276 Drury W. Cooper, New York, N.Y.
6277 Guy LeRoy Current, Bklyn., N.Y.
6278 H. A. Coussirat, New York, N. Y.
6279 A J. Graham, New York, N. Y.
6280 C. H. Leighton, Newton, Upper Falls, Mass.

Total, 273.

Applications for Transfer

Recommended for transfer by the Board of Examiners, Apr. 12, 1907.

Any objection to these transfers should be filed at once with the Secretary.

FRANCIS LYMAN GILMAN, telephone engineer, 463 West St., New York City.

EDWIN SIBLEY WEBSTER, electrical engineer, Stone & Webster, 84 State St., Boston, Mass.

CHARLES AUGUSTUS STONE, electrical engineer, Stone & Webster, 84 State St., Boston, Mass.

Associate Societies in the Engineers' Building

1. National Electric Light Association.
2. National Fire Protective Association.
3. American Street Railway and Interurban Railway Association.
4. New York Electrical Society.
5. Society of Naval Architects and Marine Engineers.
6. Municipal Engineers of the City of New York.
7. Technical Society of New York.
8. Illuminating Engineering Society.

Personal

MR. LOUIS MUHLHEIZLER has been made chief engineer of the Pittsburg and Allegheny Telephone Co., of Pittsburg, Pa.

MR. CLIFTON V. EDWARDS, patent lawyer, has removed his offices to the United States Express Building, No. 2 Rector Street, New York City.

MR. C. R. TATEM, formerly salesman Buffalo office Allis-Chalmers Company, has been appointed acting district manager of that Company's Buffalo office.

MR. GEORGE R. WOOD, Consulting Electrical Engineer, has removed from the Fulton building to enlarged quarters at 1207-8 Park building, Pittsburg, Pa.

MR. E. S. NORTHUP has been appointed by the New York civil service commission as a mechanical-electrical draftsman, and is located in the Bronx Municipal building.

MR. E. LANG, purchasing agent of the Wheeler Condenser & Engineering Co., has removed his office from 42 Broadway, to the West Street Building, West and Cedar Streets, New York.

Mr. A. W. Copley is at Mount Vernon, New York, making tests on the New York, New Haven and Hartford Railroad, for the Westinghouse Electric and Manufacturing Company.

Mr. C. H. Vom Baur has changed his address to Massena, N. Y., with the Indestructible Fibre Co. This company makes three kinds of fibre board of any size and thickness, having wood pulp as a base.

Mr. H. C. Goldrick, formerly southern sales manager of the Kellogg Switchboard and Supply Company, is now in charge of the new Canadian office of that company, located in Winnipeg. Manitoba.

Mr. H. A. Scott has left the Williamsburg Paper Manufacturing Company of Williamsburg, Pa., to accept a position as electrical engineer with the Horseshoe Forestry Company, with headquarters at Horseshoe, New York.

Mr. R. A. Langworthy has been transferred by Ford, Bacon and Davis, from Birmingham, Ala., to Nashville, Tenn. He will have charge of designing the layout for several new turbine units to be installed in the power station at Nashville.

Mr. Farley Osgood has resigned his position as general manager and chief engineer of the New Milford Power Company, the well-known hydroelectric high-tension system of Connecticut. Mr. Osgood's resignation takes effect May 31, 1907, but he does not care to divulge his future plans just at this time.

Mr. J. G. Rossman, consulting engineer, formerly of Atlanta, Ga., has returned from an extended trip to California, Northwest, and Black Hills, So. Dakota, and has taken offices in the Broad-Exchange Building, 25 Broad street, New York City, making a specialty of water power and electric developments.

Mr. R. Neil Williams, formerly assistant professor of electrical engineering, under Dr. Charles P. Steinmetz at Union University, Schenectady, New York, has returned to practical work with the General Electric Company, and is at present in the power and mining department of the Baltimore office of that company.

Mr. W. A. Blonck, consulting engineer in Chicago, has moved to larger quarters, and now occupies suite 404 Fisher Building. Mr. Blonck has recently designed a number of large industrial power plants and is now working on several hydroelectric developments in the West, as well as on various interurban railway properties.

D. W. Beldon, who for several years past has been general manager of the Phoenix Light and Fuel Company is now located at Tucson, Arizona. On the taking over of the Phoenix Light and Fuel Company by the Pacific Gas Company of Los Angeles, Cal., some time ago, Mr. Beldon became associated with the Westinghouse Electric and Manufacturing Co., taking charge of its recently opened office in the Santa Rita Building in Tucson, Arizona.

Mr. Elbert G. Allen has been transferred from the position of electrical and mechanical engineer of the Seattle Electric Company, of Seattle, Washington, which position he has held for more than four years, and is now one of the staff of the Stone and Webster Engineering Corporation. At present he is superintendent of construction of some additions which the corporation is making to the power plant of the Dallas, (Texas) Electric Light and Power Co.

Mr. Albert Spies has taken over the editorship of the Electrical Record beginning with February of this year. Immediately previous to that date, he had been editor of Cassier's Magazine, almost from the very beginning of that publication, 1893, to the end of 1906. During part of that period—January 1904, to March 1906 he had been editing in addition, the Electrical Age, serving as Vice-president to both the Cassier Magazine Company, and the Electrical Age Company.

Mr. D M. Swink has resigned his position as erecting engineer with the Baltimore office of the Westinghouse Electric and Manufacturing Co., to become superintendent of the Winchester and Washington City Railway Co., a company at present operating a lighting system in Winchester, Va., Berryville, Va., Charlestown, W. Va., and Millville, W. Va. The main station, near Millville, on the Shenandoah river, transmits at 22,000 volts, serving the towns en route to Winchester, about thirty miles.

Sir William Henry Preece, K.C.B., F.R.S., was delegated by the council of the Institution of Electrical Engineers to represent that organization at the dedicatory exercises, April 16, and 17. He also officiated as honorary chairman of the special meeting of the Institute April 15. He attended the first regular meeting held at Philadelphia, October 7 and 8, 1884, and after the International Electrical Congress in Chicago, he took part in the New York meeting, September 20, 1893. Sir William has a wide circle of warm friends in this country who will be pleased to know that he expects to revisit America in the fall. He sailed April 23 on the Carmania.

Obituary

General Eugene Griffin, first vice-president of the General Electric Company, died suddenly of apoplexy, April 11, at Schenectady. General Griffin was born in Ellsworth Maine, October 13, 1855. He was graduated from the United States Military Academy in the class of 1875, and was immediately appointed a second lieutenant in the Engineer corps of the army, serving fourteen years, and rising to the rank of captain. While a member of the engineering staff of the District of Columbia, he prepared a report on electric railways for the government. He subsequently entered the service of the Thompson-Houston Electric Company, devoting his attention to the development of the electric railway.

He returned to active service in the army during the Spanish-America war, and organized the First Regiment United States Volunteer Engineers, and was appointed to its command with the rank of a colonel. He was promoted to the rank of brigadier-general of volunteers January 21, 1899. He was elected an Associate of the American Institute of Electrical Engineers, February 7, 1890, and was transferred to the grade of Member, April 27, 1906. As a member of the Land and Building Fund Committee, he was in a position to perform effective service of great value to the Institute in which he was deeply interested. His remains were interred at West Point with full military honors.

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BRANCHES.			
Atlanta............Jan. 19, '04	A. M. Schoen.	W. R. Collier.	
Baltimore.........Dec. 16, '04	J. B. Whitehead.	C. G. Edwards.	2d Friday.
Boston............Feb. 13, '03	H. E. Clifford.	C. H. Porter.	3d Wednesday
Chicago.................1893	P. B. Woodworth.	H. R. King.	1st Tuesday after N. Y. meeting.
Cincinnati.........Dec. 17, '02	C. S. Reno.	L. Lowenberg.	
Columbus.........Dec. 20, '03	F. W. C. Bailey.	H. L. Cook.	1st Monday.
Minnesota..........Apr. 7, '02	H. J. Gille.	Barry Dibble.	2d Monday after N. Y. meeting.
Pittsburg..........Oct. 13, '02	H. W. Fisher.	H. D. James.	2d Tuesday.
Pittsfield..........Mar. 25, '04	Gilbert Wright.	S. H. Blake.	3d Thursday.
Philadelphia.......Feb. 18, '03	W. C. L. Eglin.	H. F. Sanville.	2d Monday.
San Francisco......Dec. 23, '04	C. L. Cory.	A. H. Babcock.	
Schenectady.......Jan. 26, '03	D. B. Rushmore.	E. E F. Creighton.	2d Wednesday.
Seattle............Jan. 19, '04	C. E. Magnusson.	W. S. Wheeler.	3d Saturday.
St. Louis..........Jan. 14, '03	A. S. Langsdorf.	J. H. Finney.	2d Wednesday.
Toronto..........Sept. 30, '03	R. G. Black.	L. W. Pratt.	2d Friday.
Washington, D. C...Apr. 9, '03.	Edgar Russel	Philander Betts.	1st Thursday.
UNIVERSITY BRANCHES.			
Cornell University..Oct. 15, '02	E. L. Nichols.	H. H. Norris.	1st Friday after N. Y. meeting.
Iowa State College..Apr. 15, '03	F. A. Fish.	Adolph Shane.	1st Wednesday.
Lehigh University..Oct. 15, '02	A. W. Lawson.	M. T. Saldana.	3d Thursday
Purdue University..Jan. 26, '03	C. P. Matthews.	J. W. Esterline.	Every Tuesday.
Syracuse University Feb. 24, '05	W. P. Graham	R. A. Porter.	1st and 3d Thursdays.
Univ. of Wisconsin.Oct. 15, '02	F. M Conlee.	J. W. Shuster.	4th Thursday.
Univ. of Illinois....Nov. 25, '02	Morgan Brooks.	M. K. Akers.	1st Wednesday
Worcester Polytechnic Institute, Mar. 25, '04	A. P. Chapman.	A. T. Childs	
STUDENT MEETINGS.			
Armour Institute...Feb 26, '04	C. E. Freeman	C. E. Freeman	3d Monday
Ohio State Univ....Dec 20, '02	H. C. Bartholomew	F. E. Beutler	Every Tuesday evening
Penn. State College.Dec 20, '02	C. L. Christman	H. L. Frederick	Every Wednesday
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PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

Published monthly at 33 W. 39th St., New York City, under the supervision of

THE EDITING COMMITTEE,
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Subscription. United States, Mexico and Cuba, $5 per year.
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Single copy 50 cents.
Subscriptions must begin with January issue.

Advertisements accepted from reputable concerns at the following net rates:

Space.	**Less than half year.** per issue.	**Half year.** per issue.	**One year.** per issue.
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Vol. XXVI. **May, 1907.** No. 5.

The New Constitution

AFTER the report of the Committee of Tellers at the Annual Meeting May 21, the President announced that the revised Constitution as submitted by the Board of Directors had been adopted by the affirmative vote of a majority of the qualified membership. It went into effect June 10, which is twenty days after its adoption. Existing Branches will thereafter be officially designated as Sections, and arrangements have already been made to have them reorganize under the new title. University organizations only, will be hereafter known as Branches The new Constitution is the work of the Committee on Law, with the exception of a few minor modifications made by the Board of Directors. Now that this Constitution has been adopted the revision of the By-laws must be next undertaken. The existing By-laws will remain in force until that work is completed. Should any parts be found in practice to conflict with the Constitution they may be amended by the Board of Directors, pending the more thorough revision which will require a considerable expenditure of time.

It is hoped that the Sections will avail themselves of the simple provisions embodied in the new Constitution for their representation at the Annual Convention. The Chairman of the Section, or an alternate will be recognized as an official delegate, and may have his expenditures for transportation refunded by the Institute. The Annual Convention should thus become still more national in its character, offering an opportunity for an interchange of views regarding Institute work in general, as well as development of Sections. This does not necessarily mean official reports and discussions, but general conversation between sessions which seldom gets into print, yet is recognized as one of the important features of a convention, where busy men have an opportunity to relax and are glad to give others the benefit of their experience.

The Engineers' Club

IN what has repeatedly been termed "The Gift to Engineering" Mr. Carnegie included with the national engineering societies the Engineers' Club. His purpose in the gift has been to promote social acquaintance as well as the professional advancement of engineers. While it has been generally known that nearly one-third of Mr. Carnegie's gift was utilized in the erection of the new building for the Engineers' Club, the relations of the Institute membership to that organization are not universally understood. Its name and object are defined in the Constitution, as follows:

"The Engineers' Club shall be composed of engineers and others who may be interested in or connected with the engineering profession."

As a matter of fact, its membership, both resident and non-resident, is largely made up of civil, electrical, mechanical and mining engineers, who may or may not belong to the national organizations representing those branches of the engineering profession.

The Engineers' Club being an entirely distinct organization, admission thereto is governed by its own rules, and membership in any of the founder societies does not in itself embrace any club privileges. While there is convenient means of access from one building to the other, yet the admission to the club is, of course, limited to its own members and their guests. It has been the expressed desire of those identified with the club management to make it useful to the members of the societies as far as is practicable and consistent. The membership in the club is at present between seventeen and eighteen hundred, and there are already indications that the present facilities of the club may be overtaxed on special occasions. The present officers of the founder societies are members of the club, and they will doubtless be able to arrange in many cases for extending the privileges of the club to members from a distance while visiting New York.

Many of the new relations between the societies and between the societies and the club must be the outcome of experience. There appears to be a general purpose to cooperate in such a way as to get the best results of the new opportunities which the gift provides. While each organization will develop its own individuality, yet there are many points in common where the interests of each will be promoted by general cooperation.

Editing of Discussions

SOME recent contributions compel the Editing Committee to state that gentlemen who take part in the discussions, and particularly those who do so in writing, must wholly refrain from acrimony, or personal reflections. Compliance with this imperative requirement will relieve the Editor, the Editing Committee, and correspondents themselves, from unnecessary labor and friction. The amount of text requiring editorial revision is large; the Editor or his assistants must engage in considerable correspondence with members before communications can be reduced to the ultimate facts and conclusions which it is felt should be published. This is always a source of expense and delay. The object of the discussion being to elucidate the subject of a paper, it seems possible to conduct it without acerbity, which cannot make it more illuminating. The Editing Committee intends to publish in the PROCEEDINGS nothing which is objectionable; and it will not accept contributions, however desirable for other reasons, which violate this requirement.

The Next Convention

IN this issue are many of the papers to be presented at the Niagara convention beginning June 25. Those who intend discussing them will thus have an opportunity to prepare themselves. Copies of these will also be available at the convention as well as of those received too late for immediate printing in the PROCEEDINGS. Written discussions are invited from members who cannot attend the convention. Headquarters will be at the Cataract-International Hotel, where the various sessions will also be held. Requests for reservations shou'd be made direct to the hotel. The convention program already mailed gives full information.

AMONG the important changes in the new Constitution is the provision that the terms of committees shall expire at the first meeting of the Board of Directors after the annual election. This will be June 21 1907. The object of this innovation is to provide for the earlier appointment of new committees so that they may begin their duties before the opening of the active season which will hereafter be on the second Friday in October.

The Schenectady Branch, Season 1906-7*

The Schenectady Branch has been favored this year with an exceptionally successful season and a description of some of its work may be of interest. Some of the innovations adopted to create greater interest in Institute matters at Schenectady will possibly suggest even better methods to others.

During the year there have been held a total of thirty-three meetings, at which were presented twenty-five original papers, many by noted engineers not connected with the Branch. The membership has been increased from a total of less than two hundred in the fall of 1906 to over nine hundred at the present time.

At a preliminary smoker held in September of last year, plans were laid for the season 1906-7, and it was decided to maintain a course of weekly lectures for the benefit of the Members and Associates of the Institute residing in and near Schenectady, and to others who wished to affiliate with the Branch by the payment of nominal dues to defray current expenses. A four-page prospectus was issued outlining the aims of the association and giving a partial list of speakers who had signified their willingness to address the meetings. All Members and Associates of the American Institute of Electrical Engineers were, of course, members of the Branch, but to non-members all the privileges of the Branch were extended for an annual fee of $2.00. A special student membership for men in the testing departments of the General Electric and American Locomotive companies, students at Union College, Rensselaer Polytechnic Institute, etc., was also started, for which the dues were $1.00 per year. There was no initiation fee for any class of membership. A Membership Committee was appointed, consisting of sixteen men, and an energetic campaign undertaken to interest non-members of the Institute in the work of the Branch. The result was so satisfactory that the Treasurer's report shows returns of three hundred and ninety-seven full members at $2.00 each and three hundred and forty-seven special members at $1.00 each, a total of $1141.00 received from dues during the year.

The immediate effect of the increased activity in Institute work was to bring into membership with the national body a large number of new Associates, and whereas the July membership list of the Institute for 1906 shows but one hundred and thirty-two names under Schenectady, the present membership is approximately one hundred and ninety-one, with a large number of applications still to be acted upon. It is expected that next year there will be a still further increase in membership to the national body from those who have been interested in the Branch work this year, and who will prefer to become Associates rather than remain simply Section members in 1907-1908.

The first two or three meetings of the year were opened to all who desired to attend, and the interest was so great that the High School auditorium, where the lectures were held, and which seats approximately nine hundred, was often taxed to its full capacity. After the first few lectures, however, admission was by ticket only, but members could obtain tickets for their friends without difficulty from any of the Membership Committee. These tickets to be valid had to contain the name and address of the holder, and in this way the Membership Committee obtained a list of those interested and acquired a large number of new members.

During the year, four evenings were set aside for the discussion of papers read in New York, the papers in general being abstracted by some local authority. For example, the discussion of the paper on "The Substitution of the Electric Motor for the Steam Locomotive," by Messrs. Stillwell and Putnam, read on January 25, was opened by Mr Potter at the Branch meeting of February 7, and was participated in by

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*By W. C. Andrews, Corresponding Secretary of the Schenectady Branch.

Messrs. Fortenbaugh, Slichter, Eveleth, and Dodd, of the General Electric Company, and Mr. William Dalton of the American Locomotive Company. There were twenty-five original papers presented on a wide range of subjects during the year, and four evenings were devoted to topical discussions or debates on subjects of general interest, at which many valuable original contributions were presented.

Although the closing year has been one of extreme activity from an educational standpoint, the social features have not been overlooked. Besides the informal smoker held at the commencement of the year, when the season's work was laid out, there have been two entertainments, which a large percentage of the total membership has attended, and, from all indications they were highly enjoyed. The expense of these smokers was borne entirely by the Branch, no additional assessment of any kind being made on the members.

The complete program for the season just closed was as follows:

October 5, T. C. Martin, "Technical Journalism"; October 12, E. C. Acheson, "Inventions and Discoveries"; October 20, R. W. Raymond, "Professional Ethics"; October 27, topical discussion "Thury System," Messrs. Taylor, Eveleth, Noeggerath and Wilkinson; November 2, S. A. Moss, "Gas Turbines"; November 9, topical discussion "Municipal Ownership"; A. B. Lawrence, A. V. Thompson and others; November 16, W. S. Franklin, "The Second Law of Thermodynamics"; November 23, F. O. Blackwell, "Hydro-Electric Developments"; November 30, W. S. Andrews, "Pioneer Work in Electric Lighting"; December 8, C. P. Steinmetz, "Transformation of Electric Power into Light"; (Discussion of his paper read in New York Nov. 23); December 15, topical discussion, "Metric System"; December 22, V. G. Converse, "Ontario Power Co."; January 5, E. E. F. Creighton, "Lightning Protection"; (Discussion of R. P. Jackson's paper read in New York December 28); January 12, E. J. Berg, "Parallel Operation of Alternators"; January 19, topical discussion "Industrial Betterment," Messrs. Steinmetz, Craven, Hewett. McMillan, Crane and Maxwell; January 24, Maxwell Day, "Centrifugal Fans," and H. B. Emerson, "Motor Drive for Metal and Wood Working Machinery"; January 31, E. J. Berg, "Abnormal Voltages and Currents in Transmission Lines"; February 7, discussion, "Electrification of Steam Railroads" (paper read in New York by Messrs. Stillwell and Putnam January 25), Messrs. Potter, Fortenbaugh, Slichter, Eveleth, Dodd and Dalton; February 14, W. L. Merrill, "Electricity in a Paper Mill"; February 21, C. W. Stone, "A Comparison of the Different Systems of Electric Lighting," and F. F. Barbour, "Qualifications and Duties of an Electrical Apparatus Salesman;" February 28, W. S. Moody, "Design of Transformers"; March 8, smoker in Odd Fellows' Hall; March 14, S. D. Sprong, "System of the New York Edison Co."; March 21, Richard Fleming, "The Electric Arc Lamp"; March 28, C. W. Larson, "Mine Locomotives and Mining"; April 4, "Lightning Protection" (Discussion of papers read in New York March 29), Messrs. Steinmetz, Rushmore, Creighton and DuBois; April 18, G. H. Hill, "Multiple-Unit Control of Direct Current Motors"; April 25, E. J. Berg, "Constants of Cables and Magnetic Conductors"; May 2, two papers on "Electric Hoists in Mines," one by K. A. Pauly, and the other by Eugene Eichel; May 9, C. E. Eveleth, "Electrification of the West Jersey and Seashore Railroad."; May 16, Elihu Thomson, "Panama Canal"; May 23, smoker and business meeting.

The annual business meeting and election of officers was held during the smoker of May 23. A large number of the old officers were re-elected, the result being as follows: Honorary chairman, C. P. Steinmetz; chairman, D. B. Rushmore; Vice-chairman, E. H. Anderson, A. H. Armstrong, E. A.

Baldwin, E. E. F. Creighton, William Dalton, G. H. Hill, E. B. Merriam, A. L. Rohrer, C. W. Stone; corresponding secretary, W. C. Andrews; recording secretary, J. M. Knox; treasurer, A. S. Kappella; librarian, H. E. White.

A summary of the treasurer's report for the year, presented at this meeting, is as follows:

Balance on hand, May 1906..	$135.79	
Dues collected from members	1141.00	
Total receipts...........	1276.79	$1276.79
Cost of meetings, including stereopticon, reporting, announcements, cuts for newspaper articles, membership cards, postage, janitor's service at High School, and entertainments...........	403.21	
Expenses of sending delegates to New York to attend Institute meetings..........	50.00	
Contributions to Schenectady Public Library...........	50.00	
Total..................	$503.21	503.21
Balance on hand....		$773.58

Two items of the treasurer's report are worthy of notice. One is the contribution to the Schenectady Public Library. The Institute Branch received about four years ago, a number of books and periodicals from the General Electric Engineering Society through the affiliation of that society with the Branch, and these books are maintained in special bookcases at the Public Library. Of the annual donation of the Branch, $37.50 is devoted to the purchase of new books to increase this collection, $12.50 being taken as a fee for maintaining the books in good condition and other librarian services. The selection of books is in the hands of a special committee.

In order to stimulate interest in the topical discussions as well as the other work of the Branch, delegates were appointed during the year and their expenses paid to New York to attend the regular meeting of the national body. Conspicuous interest in the work of the Branch either by valuable contributions to the discussions or otherwise was the basis on which these delegates were selected. There was the added advantage in this system of bringing non-members of the national body—they only were eligible to receive the free trips—in contact with the New York members, thereby impressing them with the advantages gained by joining the Institute.

Local Organizations

ARMOUR INSTITUTE

At a meeting of this Branch, held April 26, F. M. Sturgess gave a digest of Dr. Steinmetz's paper on "Lightning Phenomena in Electric Circuits;" also a digest of Messrs. Rushmore and Dubois' paper on "Protection against Lightning, and the Multigap Lightning-Arrester."

On May 3, C. S. Henning read an original and interesting paper on "Multiple-Unit Control," in which he explained the operation of the various systems with the aid of wiring diagrams for both alternating-current and direct-current-railways.

At the May 17 meeting of this Branch the following officers were elected for the coming year: Theodore C. Oehne, vice-chairman; Olive R. Morey, secretary. Professor J. E. Snow will act as chairman and local secretary, due to the resignation of Professor C. E. Freeman.

BALTIMORE BRANCH

This Branch held a meeting May 9, at the B. and O. Central building, Baltimore, J. B. Whitehead presiding, with a total attendance of 72. The chairman appointed a nominating committee, consisting of Messrs. W. A. Young, W. H. Vail, and S. D. Black, to present the names of members for election as officers of the Baltimore Branch for the ensuing year. Mr. W. D. Young, electrical engineer of the Baltimore and Ohio Railroad company, read a paper on the "Lighting and Electro-equipment of the Baltimore and Ohio Central Building." After the reading of this paper, and discussion, a tour of inspection was made of the building.

BOSTON BRANCH

This Branch held a meeting May 15, at the Massachusetts Institute of Technology, presided over by Professor H. E. Clifford, with a total attendance of 111. The chairman appointed the following committee to nominate officers for the ensuing year: Messrs. J. S. Codman, H. D. Jackson, N. J. Neall. Mr. L. L. Elden, electrical engineer with the Edison Electric Illuminating company of Boston, presented a paper entitled," An analysis of the Distribution Losses in a large Central Station System."

[This paper will be printed in a future issue of the PROCEEDINGS.]

UNIVERSITY OF COLORADO

During the past month this Branch has held two meetings. At the first, Mr. Bullock, of Denver, gave a talk on "The Westinghouse Apprentice System." The second meeting was a joint meeting with the other engineering societies of the University, at which Mr. G. C. Anderson, C. E., of Denver, gave an address on "The Future of Hydraulic Engineering in Colorado."

CORNELL BRANCH.

The closing meeting of the Cornell Branch for the current year was held on the evening of June 4, in the Sibley Club room. In accordance with the new Constitution, a delegate was elected to attend the Annual Convention, The preparation of By-laws for the Branch was informally discussed. It is the intention in the future to prepare simple By-laws covering local needs.

The paper of the evening was delivered by Professor Ernest Merritt upon the topic "Radioactivity." The address, with the resulting discussion, proved of great interest and gave the members a view of the latest varieties of electric conduction and other advances which have followed from the discovery of the properties of radium and other radioactive metals. The speaker pointed out that while in a commercial sense radioactivity has not "made good" scientifically, it has proved of the utmost importance. This is particularly true as regards the indirect results, especially upon the theories of the construction of matter. A most interesting suggestion was that radium may result from the disorganization of uranium and that the metal itself may simply represent one stage in a series of such disorganizations.

This meeting closes a most successful year's work for the Cornell Branch, and the members were highly pleased at the passage of the new Constitution which greatly favors the growth of the branches.

ILLINOIS

This Branch held a meeting May 1, in the electrical engineering lecture room of the Illinois University, Professor Morgan Brooks presiding, with a total attendance of 24. The following papers were presented.

"Lightning Phenomena in Electric Circuits," by C. P. Steinmetz, read in abstract by M. K. Akers of the electrical engineering department.

"Protection againt Lightning, and the Multigap Lightning-Arrester," by D. B. Rushmore and D. Dubois; abstracted by J. M. Bryant of the electrical engineering department.

A nomination committee for the election of officers for next year was appointed by the chairman. At the next meeting, May 29, the officers are to be elected.

IOWA STATE COLLEGE BRANCH

A meeting of the local Branch was held April 24 in Engineering Hall. Adolph Shane presided in the absence of Professor Fish. Thirty members and six visitors listened to the abstract of Messrs. Stillwell and Putnam's paper "On the Substitution of the Electric Motor for the Steam Locomotive" given by Mr. A. H. Hoffman. The importance and significance of the paper was clearly recognized, several papers at previous meetings having discussed those railroads that are at present being electrified or have recently been electrified.

A business meeting was held at the conclusion of the paper and discussions, the purpose of which was to vote on the proposed Constitution of the local Branch. It was found that the old Constitution did not adequately meet the present requirements, the executive committee having been authorized to draw up a new one which was presented before the members for action at this meeting. With a few minor changes the proposed Constitution was unanimously adopted.

Twenty-nine members and two visitors attended the meeting on May 8. Abstracts of the discussions on Messrs. Stillwell and Putnam's paper " On the Substitution of the Electric Motor for the Steam Locomotive " were given as follows:

Mr. Soukup—Messrs. Sprague and Lamme's discussion.

Mr. Uhl—Messrs. Arnold and Potter's discussions.

Mr. Whitacre—Messrs. Lyford and de Muralt's discussions.

Mr. Stahl—Messrs. McClellan and Slichter's discussions.

Mr. Hurd—Messrs. Whitehead Stillwell, and Sprague's discussions.

Mr. Scherling—Mr. Calvert Townley's discussion.

Mr. Tunis—Messrs Stillwell and Putnam's closing statements.

Lively discussion by the local members followed, it being observed that some difference of opinion existed among the gentlemen who presented their discussions at the New York meeting.

There will be an election of officers at the next and final meeting of the local Branch for the present college year.

The last meeting of the Branch for the present year was held Wednesday evening, May 23, in Engineering Hall. The meeting was called to order by Professor Fish. The first paper of the evening was presented by Mr. G. E. Marsh on " Theory of Commutation." The paper took up the mathematical discussion of the factors which are involved in the process of commutation. It was shown in the final equation that after the various factors of inductance, mutual inductance, resistances of the coils under commutation, and contact resistances were either determined or assumed, that it required but the insertion of a given value of time to determine the value of the current in the short-circuited coil at that instant. Considerable discussion followed the paper chiefly as to the value of the final equation in design.

The second paper of the evening was an abstract of Mr. D. McFarlan Moore's paper on " Light from Gaseous Conductors within Glass Tubes—The Moore Light." This was given by Professor Adolph Shane. Much interest was manifested as indicated by the discussion which followed. These took the trend of comparison of the Moore Light with other forms of illumination.

The election of officers for the next term followed the presentation of the papers. The results showed the re-election of Professor Fish as chairman, and Professor Shane as secretary of the Branch. Messrs. Pullen, Halpenny, and Shaw were elected members of the executive committee; and Messrs. Wills, Thompson, and Dewey were elected members of the social committee.

There is some cause for gratification at the increase of attendance and interest shown at the meetings held during the past college year. It is hoped that next year the meetings may prove even more valuable.

MINNESOTA BRANCH

A meeting of the Minnesota Branch was held in the offices of the St. Paul Gas Light Co., May 13. The evening was devoted to the subject of lightning protection. A. L. Abbott reviewed the Institute paper by Dr. Steinmetz, and Professor G. D. Shepardson took up the paper by Messrs. Rushmore and Dubois.

Edward P. Burch opened the discussion. He pointed out the lack of consistency of lightning-arrester manufacturers in insisting on a straight, non-inductive path to the arrester, and then introducing an intricate, zigzag path through the arrester itself. He believed that arresters should have the gaps and connections in a straight line, though this would on high potentials require the use of a tower for their installation. Another recommendation was that instead of making the gaps uniform they could be made wider on the line side, and narrower on the ground side of the arrester, with the effect of making the potential gradient rectilinear.

F. R. Cutcheon stated that in one plant the lightning-arresters had been placed in a horizontal position, which was believed to be an advantage, as it made the capacity to ground the same through the entire arrester.

UNIVERSITY OF MONTANA

The University of Montana Branch, at Missoula, Montana, authorized by the Board of Directors to hold student meetings, was organized on May 21, 1907, with Robert Sibley, chairman, and S. R. Inch, secretary. At its first meeting the following officers were elected:

F. S. Lorentz, chairman; J. A. Thaler, secretary; C. M. Fisher, treasurer The time of meeting will be the first Friday of each month during the school year.

PENNSYLVANIA STATE COLLEGE

The officers of this Branch for the present term, are: chairman, E. W. Nick; secretary, S. W. Price. Meetings are held every Wednesday, with an average attendance of twenty-five or thirty. Four speakers are scheduled for each week, and the topics presented are taken from the PROCEEDINGS and other current technical magazines.

PHILADELPHIA

The thirty-seventh meeting of the Philadelphia Branch was held on May 13, at the regular meeting place, the Engineers' Club of Philadelphia. The meeting was preceded by the usual dinner. As this was the last formal meeting for the year, the next meeting being of an informal nature, the opportunity was taken for thanking Mr. L. J. Costa who has had charge of the monthly dinners. These dinners have been a great success throughout the year, the attendance varying from thirty-five to sixty. They have had a large part in making the Philadelphia Branch the active branch that it is.

At the suggestion of the Branch Council a motion was put through creating the office of assistant secretary for the Philadelphia Branch, so that this place will be filled at the coming meeting in June.

The paper of the evening on " Some Newly Observed Manifestations of Forces in the Interior of a Conductor, and their Utilization," was presented by Dr. E. F. Northrup The subject was entirely new and was presented for the first time before any scientific body. It was received with much interest by the members. The ingenious method by which Dr. Northrup makes use of his discovery for measuring large currents gives it an immediate practical value.

[This paper will be printed in a future issue of the PROCEEDINGS.]

PITTSBURGH.

At the meeting of this Branch, May, 14, fifty-six members and visitors were present. Mr. McPherson read an interesting paper on gas engines in central station work. The paper was based on actual experience obtained in the Duquesne Light Plant in Pittsburgh, and was supplemented by a short talk by Mr. J. R. Bibbins.

Mr. S. P. Grace abstracted a paper he presented at a New York meeting, and showed a number of lantern slides illustrating different details in wire construction of telephone lines. An interesting discussion followed.

Mr. H. W. Fisher announced that this would be the last Branch meeting to be held this season, and that meetings would be resumed next fall. He also urged the members to attend the annual convention at Niagara Falls.

PURDUE

This Branch held a meeting on April 30, in the electrical building at Purdue University, Mr. G. B. Walker presiding, with a total attendance of fifty-one. After the adoption of an amendment to the constitution of the Engineering Review Board, the following officers were elected: R. S. Webb, vice-chairman; C. A. Jaqua, assistant secretary; P. F. Harbolt, treasurer. Mr. C. R. Moore then talked on the subject "Electrolysis Due to Grounded Return Circuits," followed by discussion.

Another meeting of this Branch, held May 14, at the same place and with the same presiding officer, had an attendance of seventy. Bills were presented and ordered paid, after which, Mr. G. H. Kelsey, Purdue '00 at present general superintendent of the Indiana Union Traction company, gave an address on "Organization and Methods in Interurban Railways."

SCHENECTADY

At the election of officers for this Branch, held May 23, Mr. D. B. Rushmore was elected chairman, and Mr. W. C. Andrews corresponding secretary.

[A history of the Schenectady Branch for the year 1906-7 is printed elsewhere in Section I of this issue.]

SEATTLE

This Branch held a meeting at Seattle, May 18. presided over by Professor C. E. Magnusson, with a total attendance of ten. Professor C. Edward Magnusson was chosen official delegate of the Branch to the A.I.E.E. convention, to be held at Niagara Falls, June 25–28, 1907.

An original paper, on "The Largest Motor in Seattle," was illustrated with photographs. Mr. Geo. H. Moore presented the paper, and Mr. F. G. Simpson furnished the photographs. Discussion by Messrs. Magnusson, Whipple, and Joslyn.

SYRACUSE UNIVERSITY BRANCH

The final meeting for the college year was held on Thursday evening, May 16. Nine members and eight visitors were present. The executive committee for the coming year was elected. It consists of Professor W. P. Graham, president of the Branch; R. A. Porter, secretary, and three student members, E. C. Myers, H. V. Brown, and R. E. Allen, of the class of 1908.

A discussion of the Moore Light was led by E. C. Myers, who abstracted the Institute paper on this subject.

TORONTO

This Branch held a meeting on May 10 presided over by Mr. R. G. Black. On motion of Mr. W. A. Bucke, seconded by K. L. Aitken, the executive committee for the ensuing term will consist of Messrs. K. L. Aitken, chairman; H. W. Price, Edw. Richards, and W. G. Chace. Secretary, L. W Pratt.

After the executive meeting, Mr. Wills Maclachlin read an original paper on "Single-Phase Electric Railways," which proved very interesting. A lively discussion followed by Messrs. Aitken, Black, Boyd, Lamb, Chace, Rosebrugh, Bucke, Fairbairn, Pratt.

WASHINGTON UNIVERSITY

This Branch held a meeting April 3, at Washington University, Professor A. S. Langsdorf presiding, with an attendance of thirteen. Mr. W. E. Liggett presented a paper on "Incandescent Lamp Manufacture," and Mr. M. C. Cave followed, with "The Induction Motor Operated as an Asynchronous Generator." Professor A. S. Langsdorf gave short discussions on both papers, and general discussion followed.

WASHINGTON UNIVERSITY

A meeting of this Branch was held on Thursday afternoon, May 2, 1907.

An abstract of the paper by Dr. Steinmetz on "Lightning Phenomena in Electrical Circuits" was given by Geo, Mezger, W. U. '07.

G. L. Evans, W. U. 07', abstracted Mr. Creighton's paper "New Principles in Design of Lightning Arresters."

A paper on "The Compounding of Alternators" was read by R. W. Lamar, W. U. '07.

A discussion of the operation of alternators in parallel followed, results obtained by Messrs. Lamar and Mezger in connection with their thesis being shown.

WORCESTER POLYTECHNIC INSTITUTE

The regular meeting of the Branch was held Monday evening, April 29, 1907, in the electrical engineering lecture room, Salisbury laboratories. President Chapman called the meeting to order and introduced C. A Adams, Professor of electrical engineering at Harvard University, who spoke on the subject, "The Synchronous Motor." The first part of the meeting was taken up in explaining a mechanical analogue which is of great value in forming a physical conception of the phenomena taking place in the synchronous motor. The latter part of the lecture was devoted to the Blondel diagram. The meeting was very interesting and instructive and the Branch wishes to express its appreciation of Professor Adams' kindness.

The annual election of officers was held at the regular meeting of the Branch, May 20, 1907. The following officers were chosen for the ensuing year:

Mr. L. W. Hitchcock, '08, president; Mr. C. E. Putnam, '09, vice-president; Mr. Sidney W. Farnsworth, P. G., secretary-treasurer. Executive Committee: Mr. L. W. Hitchcock, 08'; Mr. C. E. Putnam, '09; Mr. Sidney W. Farnsworth, P. G.; Professor Harold B. Smith; Mr. Roger E Coolidge, '08; Mr. Edmund B. Haslop, '09.

Due to the non-completion of the lecture room in the new electrical building, the meeting was held in the mechanical engineering lecture room, engineering laboratories.

After the business meeting, the following members of the post-graduate and senior classes gave abstracts of their theses.

Mr. Joseph T. Butterfield, '07, "Oscillographic Records of Telephonic Waves."

Mr. Howard H. Haynes, '07, "Types of Air Brakes."

Mr. Leon I Thomas, '07. "Clark Automatic Telephone System."

Mr. E. G. Scott, P. G., "Electric Railway Control."

Mr. F. W. Stinson, '07, "Primary Batteries."

Mr. Percy P. Smith, '07, "Rail-Bond Testing."

Minutes of Meetings of the Institute

A special meeting of the Institute in honor of Sir William Preece, K.C.B., F.R.S., was held in the Auditorium of the Engineers' Building on April 15, 1907, the eve of the dedicatory ceremonies With this meeting, and the illumination of the building, inside and outside, the dedicatory exercises were formally begun.

President Sheldon called the meeting to order at 8:15 p.m.

The Secretary announced that at the close of the meeting an opportunity would be given to all present who desired, to inspect the building. President Sheldon then introduced Past-president T. Commerford Martin, chairman of the Land and Building Fund Committee, who said:

A great many years ago, in England, there was a famous singer named Braham, and his most popular and famous song was "There's a good time coming." He was in the west of England one night, in Bristol, singing the song, and was received with uproarious applause and with several encores. They had pretty bad seasons in the west of England, that year and an old farmer got up in the gallery and said, "I heard your song—There's a good time coming—say, mister, won't you kindly fix the date." To-night we meet in Dreamland. We fixed this date a great many years ago. In the Institute TRANSACTIONS for 1885 you will find some reference to the building in which we now meet. Our dreams have come true, we have made good, but there is also a financial aspect in these matters. When the American Institute of Electrical Engineers took up its share of obligation in connection with the Engineers' Building, it faced a debt of about $185,000. To-night, as chairman of the Land and Building Fund Committee, I have the honor to report that your committee has succeeded in securing pledges for close upon $165,000. Of that amount $125,000 is now cashed into the treasury of the Institute. With the balance which the Institute has had on hand, the Institute meets dedication day with a balance to the good. Personally, as chairman of the Institute Land and Building Fund Committee, I consider whatever balance it has in hand is sacred, and I want you gentlemen who have not yet subscribed to the Land and Building Fund—there are far too many of you—to make good and help us raise the remaining amount due, so that within a short time the balance the Institute now has will remain intact, and the $185,000 we started out to raise will be $200,000, and then the Institute will be equipped to do its work fairly and efficiently. I ask any of you who have not yet subscribed to do your fair share, with your colleagues and fellow-members, and help the committee in its work

PRESIDENT SHELDON: It is a great honor and a great pleasure for me to yield the chair to-night to one who has been an Honorary Member of the Institute ever since its organization, one who attended its first professional session and took part in the discussion, one who is a Past-president of the Institution of Electrical Engineers of Great Britain, Sir William Henry Preece.

SIR WILLIAM PREECE: We all of us are actuated at times by certain ambitions and I am bound to say that almost all the ambitions that I formed in my life have been attained; but the one ambition which appeared to me to be so infinitely impossible that I scarcely ever dreamed of securing it—I do not know that I ever dreamed of securing it—was that of being present in New York and taking the chair at a meeting of the American Institute of Electrical Engineers. Now, I may tell you at once that of all the appointments I have ever held, there is none that I have held in greater honor or greater satisfaction than that of being an Honorary Member of the American Institute of Electrical Engineers; and that principally because Lord Kelvin and myself are the only two honorary members.

I have been associated with Lord Kelvin since the year 1856. I know him well, and he, like myself, has been twice President of the Institution of Electrical Engineers of Great Britain. We followed each other. He is 83, I think, and I am ten years younger. I was 73 on my last birthday. If I were to visit this country a little more frequently I think I should have a very great prospect of reaching that age which appears to be necessary to secure a third election to the Presidency of the Institution.

I do not know why it is in this atmosphere of yours—I do not know whether it is the air we breathe, or whether it is the men with whom we are brought in contact—there is something electrical about things here. That electricity may be formed by contact, or if it is atmospheric electricity which we breathe here, that may be the reason; but there are two facts that have been evident to me every time I have been here—I require less sleep and do three times as much work. It is commonly said that there is something in the American habits and methods that lick creation, and that the old fogies in England cannot get through the amount of work that the American does; but I doubt very much if there is much difference between the American and the

Englishman, when the Englishman gets here. When the American gets to the other side, he is about the worst fellow in the world to keep an appointment. I make a joke of it—I never knew an American to keep an appointment promptly. He is mercurial, excited by electricity, the electron is inside of every American, millions of electrons keep him stirring and active, and we feel just the same when we get here, at least I do.

I am proud to take this chair to-night. I shall have something to say on the paper I am going to call upon Dr. Potts to read. I say this, because I feel not only proud to take the chair, but I shall, as I am not experienced in your ways of conducting business, ask you to allow me to conduct the business this evening as though it were a meeting of the Institution of British Engineers. The President of the British Institution of Civil or Electrical Engineers is an autocrat, and he is much more powerful than your President in the States.

Mr. Louis M. Potts of Baltimore then read a paper entitled "The Rowland Telegraphic System." The paper was discussed by Messrs. R. W. Pope, A. E. Kennelly, Wm. Maver, Jr., H. G. Stott, E. F. Northrup, Gano Dunn, Sir Wm. Preece.

The 218th regular meeting of the American Institute of Electrical Engineers was held in the Auditorium of the Engineers' Building, 33 West Thirty-ninth street, New York, Friday, April 26, 1907. President Sheldon called the meeting to order at 8:20 o'clock P.M.

The Secretary announced that at the meeting of the Board of Directors held during the afternoon there were 154 Associates elected as follows:

ALMOND, FREDERICK CHARLES, Engineer, North Dakota Independent Telephone Co., Fargo, N. D.

BAGNALL, E. J., General Manager, Adams, Bagnall Electric Co., 2049 E. 100th St., Cleveland, O.

BARSTOW, WILLIAM AUGUSTUS, Superintending Electrical Engineer, Union Iron Work Co., San Francisco; res., Larkspur, Cal.

BATEMAN, GEORGE FREDERICK, Student, Cooper Union Day School of Technical Science; res., 213 W. 34th St., New York City.

BATHGATE, OWEN HAMILL, Mechanical Assistant, Penn. New York and Long Island R.R. Co. Power Station, Long Island City, N. Y.

BAYLEY, JOHN F., Constructional Engineer, Brush Electrical Engineering Co., Falcon Works, Loughboro, Eng.

BEAUBIEN, EDGAR FRANCIS, Patent Department, Western Electric Co., 259 So. Clinton St., Chicago; res., Wilmette, Ill.

BERGELIN, THORSTEN, Assistant Engineer, Utah Light and Railway Co.; res., 571 So. Main St., Salt Lake City, Utah

BERGENDAHL, CHRISTIAN JOHAN GUSTAF, Electrical Inspector, Underwriters' Association of the Middle Department, Reading, Pa.

BERN, EMIL GUSTAVUS, Electrical Engineer, General Electric Co., Schenectady, N. Y.

BERNHARD, FRANK HUGO, Instructor in Electrical Engineering, Armour Institute of Technology; res., 1534 Fulton St., Chicago, Ill.

BOLSER, MILES ORTON, Student, Iowa State College, Ames, Iowa.

BOWEN, BENJAMIN JAMES, Equipment Engineer, New England Telephone and Telegraph Co., 101 Milk St., Boston, Mass.

BOYD, HUGH HARKNESS, Assistant Electrical Engineer, Canadian Pacific Railway Co., Winnipeg, Canada.

BRANCH, GEORGE IRVING, Draughtsman, Electrical Department, N. Y. C. and H. R. R.R. Co., res.; 298 Prospect Place, Brooklyn, N. Y.

BREED, EVERETT MARK, District Manager, Allis-Chalmers-Bullock Co., Ltd., Vancouver, B. C.

BROWN, HARRY WAGNER, Electrician, Rocky Mountain Bell Telephone Co., Butte, Mont.

Brown, Wilfrid James, Repair Electrician, Shawinigan Water and Power Co.; res., Cascade Inn, Shawinigan Falls, Can.

Browne, Wilfred Hall, Chief Clerk, Contract Department, Georgia Railway and Electric Light Co., Atlanta, Ga.

Brownell, Frank Wilbur, Hudson River Telephone Co., Goshen, N. Y.

Butler, William, Electrical Engineer, Lockport Gas and Electric Light Co., 107 Grand St., Lockport, N. Y.

Byers, Vernon Clyde, Assistant in Engineering Department, J. G. White and Co., 43 Exchange Place, New York City.

Campbell, John M., General Manager, Buffalo, Lockport and Rochester Railway, Kingston, Ont.

Carle, Ray Arthur, Erecting Engineer, Westinghouse Electric and Mfg. Co., 1502 Continental Trust Bldg., Baltimore, Md.

Carroll, Louis Warden, Telephone Engineer, Western Electric Co., Chicago; res.,, Riverside, Ill.

Cary, Charles Reed, Assistant Engineer, Penn., New York and Long Island R.R. Co., New York City; res., 1 Garden St., Montclair, N. J.

Cauchois, Reginald Wadsworth, Student, Columbia University; res., 458 W. 144th St., New York City.

Child, Roland Speakman, Instructor, Brooklyn Polytechnic Institute; res., 22 Garden Place, Brooklyn, N. Y.

Clement, Henry Chamberlain, Assistant Engineering Department, J. G. White & Co.; res., 66 W. 9th St., New York City.

Corey, Stewart Clark, Assistant in Electrical Department, J. G. White & Co., 43 Exchange Place, New York City; res., 156 Broad St., Newark, N. J.

Coffin, Leslie Roland, Statistical Dept., Stone and Webster, 84 State St., Boston; res., 1136 Hancock St., Quincy, Mass.

Coleman, Edward J., Superintendent, N. Y. City Interborough Railway Co.; res., 2004 Washington Ave., New York City.

Conrad, Nicholas John, Electrical Engineer, Testing Department, Chicago Edison Co., 139 Adams St., Chicago, Ill.

Cooper, Leo Henry, Switchboard Installer, Tri-State Telegraph and Telephone Co., Minneapolis, Minn.

Cravens, George Waverley, Engineer, General Electric Co., Schenectady, N. Y.

Crawford, Magnus Tate, Draftsman, Seattle-Tacoma Power Co., University Station, Seattle, Wash.

Crowell, Luther Alberto, Salesman, Westinghouse Electric and Mfg. Co., 716 Board of Trade Bldg.; res., 39 Concord Sq., Boston, Mass.

Daniels, Nathan H., Jr., Stone and Webster, 84 State St., Boston, Mass.

Day, Thomas Henry, Electrical Inspector, Hartford Board of Fire Underwriters, 27 Pliny St., Hartford, Conn.

DeBaufre, William Lane, Student, Lehigh University; res., 713 Broadway, So. Bethlehem, Pa.

Eaton, Ralph Waldo, Commercial Engineer, Westinghouse Electric and Mfg. Co.; res., Technology Chambers, Boston, Mass.

Elliott, Howard Stickney, Instructor in Electrical Engineering, University of Wisconsin; res., 707 State St., Madison, Wis.

Elwell, David, Engineer, Railway Construction Department Westinghouse Electric and Mfg. Co., Pittsburg, Pa.; res., 7 Fairview Pl., New Rochelle, N. Y.

Ely, Charles Cadwallader, Constructing Engineer, Kansas City and Western Railway, Rosedale Station, Kansas City, Mo.

Emery, Loren, Draftsman, Stone and Webster, 84 State St.; res., 131 Newbury St., Boston, Mass.

Farrow, Percival Robert, Chief Operator, Kammistiquia Power Co., Kakabeka Falls, Ont.

FERRY, MONTAGUE, Engineer, S. G. McMeen; res., 787 Market St., San Francisco, Cal.

FINNEY, ALFRED CARREL, Switchboard Inspector, General Electric Co.; res., 45 Front St., Schenectady, N. Y.

FISCHER, ADOLPH LOUIS, Assistant, Transformer Department, Thomson, Houston Electric Co., W. Lynn; res., 44 Oliver St., Malden, Mass.

FLEET, JAMES A., General Superintendent, Consolidated Electric Light Co., Portland, Me.

FLESHIEM, ROBERT STEPHENSON, Sales Engineer, Allis-Chalmers Co., 1505 First National Bank Bldg., Cincinnati, O.

FORMAN, PARIS RALPH, Mechanical Engineer, Burdett, Rowntree Mfg. Co., 85 W. Jackson St.; res., 735 Princeton Ave., Chicago, Ill.

FOSTER, WILLIAM JAMES, Design Engineer, General Electric Co.; res., 2 Douglas Road, Schenectady, N. Y.

GARWOOD, HOMER DEWITT, Assistant Engineer and Draftsman, Westinghouse, Church, Kerr & Co., Louisville, Colo.

GAY, FREDERICK WALDO, Mechanical Engineer, J. G. White and Co., 43 Exchange Pl.. New York City.

GILCHRIST, EDWARD L., Engineer, Potomac Electric Power Co , Washington, D. C.

GRAHAM, FRANK WALDRON, Superintendent of Construction, Department ment of Electricity, Jamestown Exposition, Pine Beach, Va.

GREENE, EVERETT LENT, Electrical Engineer, Westinghouse Electric and Mfg. Co., 245 39th St., Brooklyn, N. Y.

HAISLIP, R. A., 204 Sherwood Ave., Staunton, Va.

HALL, GEORGE RAYMOND Assistant Engineer, Westinghouse, Church, Kerr and Co., 10 Bridge St., New York City; res., 491 Classon Ave., Brooklyn N. Y.

HALL, WILLIAM ALEXANDER, Draftsman, N. Y. C. and H. R. R.R. Co.; res., 126a W. 127th St., New York City.

HARPER, JOHN LYELL, Chief Engineer, Niagara Falls Hydraulic Power and Mfg. Co., Niagara Falls, N. Y.

HEWITT, HOWARD BEARLEY, Laboratory Assistant, Albert B. Herrick, Ridgewood, N. J.

HILL, JOSEPH S., Chief Engineer Department of Interior, 8th and E Sts. N. W. res., The Ednor, 2118 P St. N. W., Washington, D. C.

HISS, WILLIAM JACOB, JR., New York Telephone Co., 15 Dey St.; res., 357 W. 115th St., New York City.

HOLDEN, CHRISTOPHER, Assistant Electrical Engineer, Carnegie Library, Power Construction Dept., Winnipeg, Man.

HOLLAND, WAYMAN A., JR., Tester, General Electric Co.; res., 637 Terrace Pl., Schenectady. N. Y.

HOLSTEIN, OTTO, District Inspector, Postoffices and Telegraphs, Bureau of Posts, Ormoc Leyte, P. I.

HONEYMAN, PAUL DEPUE, Division Construction Superintendent, New York Telephone Co., 15 Dey St., New York City; res., 155 Winthrop St., Brooklyn, N. Y.

HOOKER, HENRY KEENE, Clerk, N. W. Harris & Co., Boston; res., Wellesley Hills, Mass.

HORTON, WALTER H., Superintendent and Engineer, Rutland Railway Light and Power Co., Rutland, Vt.

HOUSE, ROBERT CLEMENTS, Inspector on Electrical Subways, L. B. Stillwell, 100 Broadway; res., 306 W. 140th St., New York City.

HOVEY, ALBERT FREDERICK, Cable Engineer, Interborough Rapid Transit Co.; res., 210 W. 107th St., New York City.

HOWELL, ROBERT PHILIP, JR., First Lieut. Corps of Engineers, U. S. Army, Washington Barracks, Washington, .D C.

HULL, HERBERT LADSON, Traveling Electrical Salesman, Ewing Merkle Electric Co., Fort Worth, Tex.

HUMPHREY, ROBERT GUY, Engineer, Curtis and Hine, Colorado Springs, Colo.

Hurd, Benjamin, President, Hurd and Haggin, 316 Hudson St., New York City; res., Nutley, N. J.

Hynes, Wildrie Freeman, Construction Engineer, Electrical Department, Allis-Chalmers Co. 71 Broadway, New York City.

Iremonger, Robert S., Engineer, N. Y. and N. J. Telephone Co., 547 Clinton Ave.; res., 319 Quincy St., Brooklyn, N. Y.

Jones, Lewis Charles, Construction Engineer, Chicago Telephone Co., 203 Washington St.; res., 28 Buena Vista Terrace, Chicago, Ill.

Keeler, Nelson Bertrand, Electrical Engineer, U. S. Engineering Department, 11 West St., New London, Conn.

Kendall, William Roy, Consulting Electrical Engineer, Weeks and Kendall, 605 New Nelson Bldg., Kansas City, Mo.

Kerins, John Stewart, Student Brooklyn Polytechnic Institute; res., 993 Summit Ave., New York City.

Larkin, Fred V., Engineer, Telluride Power Co., Ames, Colo.

Leland, George Benton, Superintendent, Stamford Gas and Electric Co., Stamford, Conn.

Loquin, Alexander J., Draftsman, Westinghouse Electric and Mfg. Co., Pittsburg; res., 1169 South Ave., Wilkinsburg, Pa.

Maddocks, William Samuel, Erecting Engineer, Westinghouse Electric and Mfg. Co., 730 Board of Trade Bldg., Boston; res., 10 Chandler St., W. Somerville, Mass.

Manley, John Charles, Assistant Construction Superintendent, Chicago Edison Co., 139 Adams St.; res., 5704 S. Peoria St., Chicago, Ill.

Martin, John, Assistant Designing Engineer, British Thomson-Houston Co., Ltd.; res., Belgrave, Rugby, Eng.

Masters, Wilford Thompson, Superintendent, Power Distribution, Boston Elevated Railway Co., 439 Albany St.; res., 174 W. Brookline St., Boston, Mass.

McCurdy, George Alexander, Electrical Engineer, Madison Sq. Theatre; res., 8 W. 66th St., New York City.

McQuarrie, J. L., Assistant Chief Engineer, Western Electric Co., 259 So. Clinton St., Chicago, Ill.

Mickey, Robert Kinsely, President and General Manager, Novelty Incandescent Lamp Co., Emporium, Pa.

Miller, Angus Kenneth, Assistant Engineer, Brooklyn Rapid Transit Co.; res., 85 Clinton St., Brooklyn, N.Y.

Montgomery, George Archibald, General Superintendent, Montgomery Light and Water Power Co., Montgomery, Ala.

Morgan, Joseph, Consulting Engineer. Cambria Steel Co., Westmont, Johnstown, Pa.

Morgans, Frank Davis, Member of firm and Chief Engineer, H. L. Roper and Co.; res., 501 Wyoming St., El Paso, Texas.

Moses, Percy Lawrence, Assistant Engineer, Stone and Webster at Stoughton Gas and Electric Co.; res , 747 Washington St., Brookline, Mass.

Murphy, Francis Hayes, Professor of Electrical Engineering, Highland Park College, Highland Park, Des Moines, Ia.

Musil, Louis Frederick, H. L. Doherty and Co., 60 Wall St., New York City.

Nichols, George Brown, Electrical Draughtsman, Board of Education, Park Ave. and 59th St., New York City; res., 1642 41st St., Brooklyn, N. Y.

Nielsen, Axel, Inspector, Westinghouse Electric and Mfg. Co.; res., 162 Plane St , Newark, N. J.

Noble, Irvine Morrison, Operating Department, Gould Storage Battery Co., 341 Fifth Ave ; res., 82 W. Washington Pl., New York City.

Norcross, Arthur Floyd, Student, University of Minnesota; res., 3122 Clinton Ave., Minneapolis, Minn.

Northmore, Emanuel Richard, Superintendent Los Angeles Gas and Electric Co.; res., 1530 Winfield St., Los Angeles, Cal.

Nowell, John Chase, Superintendent of Plant, Bell Telephone Co., and Delaware and Atlantic Telegraph and Telephone Co., 17th and Filbert Sts., Philadelphia, Pa.

Noyes, Frank Albert, Assistant Electrical Engineer, Rio Janeiro Light and Power Co., Rio Janeiro, Brazil.

Osgood, Isaac, Inspector, Underwriters Bureau of New England; res., 8 Albion St., Lawrence, Mass.

Otis, Henry Bailey, Manager, Chicago Office, Cutter Electrical and Mfg. Co., 636 Marquette Bldg.; res., 793 Washington Boulevard, Chicago, Ill.

Peterson, Jesse, President and Manager, United Insulated Fibre Co., Lockport, N. Y.

Pitman, Harry M., Manager, Calistoga Electric Light and Power Co., Calistoga, Cal.

Potosky, Walter David, Engineer, Harry Alexander, 18 W. 34th St.; res., 15 W. 91st St., New York City.

Putnam, Joseph Warren, Assistant Engineer, Toronto and Niagara Power Co.; res., 758 King St. East, Hamilton, Ont.

Ralston, Joseph H., Contracting Engineer; res., 506 E. Third St., Albany, Ore.

Reilly, John Joseph, Assistant Foreman, Meter Department, Philadelphia Electric Co., 122 Arch St.; res., 2209 W. Thompson St., Philadelphia, Pa.

Reimers, Frederick William, Electrical Engineer, J. G. White and Co., in the Tri-City Railway and Light Co., 1136 2d Ave., Rock Island, Ill.

Rionda, Manuel Enrigne, Partner and Director, Czarnikow MacDonald & Co., 112 Wall St.; res., 141 West 93d St., New York City.

Rodenbaeck, George Albrecht, Assistant, Massachusetts Institute of Technology; res., 161 Massachusetts Ave., Boston, Mass.

Rowntree, Harold, Secretary, Burdett Rowntree Mfg. Co., 85 W. Jackson St.; res., 7321 Princeton Ave., Chicago, Ill.

Rupe, Edwin Hervey, Telephone Engineer, Kellogg Switchboard and Supply Co., 1456 Leland Ave., Chicago, Ill.

Rush, Harry Speer, Testman, General Electric Co.; res., 1 Eagle St., Schenectady, N. Y.

Ryan, Edward James, Draftsman, City Engineers' Office; res., 211 W. Warren Ave., Detroit, Mich.

Schmeisser, Ernest Gail, Assistant Electrical Engineer, with George Gibbs, Penn., N. Y. and L. I. R.R. Co., 10 Bridge St.; res., 10 W. 128th St., New York City.

Seaman, Harold Hibbard, Manager, Electric Storage Battery Co., 1127 Candler Bldg., Atlanta, Ga.

Seaver, James Thatcher, Chief Draftsman,, N. Y. C. and H. R. R.R. Co., Electrical Department, 335 Madison Ave.; res., 147 W. 127th St., New York City.

Shepard, Francis Henry, Special Representative, Westinghouse Electric and Mfg. Co., 11 Pine St., New York City.

Smith, Daniel Arthur, Head of Electrical Department, Tuskegee Institute, Tuskegee, Ala.

Smith, Raymond Westhorpe, Inspector, N. Y. C. and H. R. R.R. Co., Engineering Department; res., 361 W. 22d St., New York City.

Smith, Vinton, Student, Brooklyn Polytechnic Institute; res., 34 South Oxford St., Brooklyn, N. Y.

Solomon, Isaac Rosh, Instructor in Electrical Engineering, University of Pennsylvania, Engineering Department; res., 3408 Sansom St., Philadelphia, Pa.

Spalding, Edward Burson, Draftsman, Signal Engineering Department, Great Northern Railway, St. Paul, Minn.

Stanley, George James, Electrical Engineer, Aluminum Co. of America; res., Poqueto Club, Parnassus, Pa.

Stebbins, Rowland, Engineering Salesman, Westinghouse Electric and Mfg. Co ; res., 6 E. 41st St., New York City.

Stein, Herman Kroberger, Erecting Engineer, Westinghouse Electric and Mfg. Co., 730 Board of Trade Bldg., Boston, Mass.

Stevens, Oscar Egerton, General Railway Signal Co., Buffalo, N. Y.

Stoll, Clarence Griffith, Telephone Engineer, Western Electric Co., 259 So. Clinton St., Chicago, Ill.

Sturges, Harry Wilton, Electrical Engineer, American Tool and Machine Co. of Boston; res., Pierce Hall, Cambridge, Mass.

Sundheimer, Arthur Isaac, Student, Columbia University; res., 234 W. 137th St., New York City.

Sutton, Frank, Consulting Electrical Engineer, 91 Wall St., New York City.

Tenney, Edgar Lamont, Draftsman, Indiana Steel Co., 251 Montrose Boulevard, Chicago, Ill.

Thayer, Burdett Cordale, Westinghouse Electric and Mfg. Co., 730 Board of Trade Bldg., Boston; res., West Medford, Mass.

Thomas, George Carlyle, Engineer, Singer Mfg. Co.; res., 143 Beach St., Bridgeport, Conn.

Thompson, Albert Reese, New York Edison Co., 55 Duane St.; res., 226 W. 105th St., New York City.

Tozer, Charles Adelbert, Telluride Power Co., Ames, Colo

Uzzell, George Walter, Student, University of Minnesota; res., 1901 University Ave., Minneapolis, Minn.

Valentine, Frederic Palmer, Engineer of Traffic, New England Telephone and Telegraph Co., 101 Milk St., Boston, Mass.

Walton, Percy James, Switchboard Inspector, General Electric Co.; res., 2 Eagle St., Schenectady, N. Y.

White, Henry Stevens, Assistant Superintendent, Greenville Carolina Power Co., Greenville, S. C.

Whiting, Max Albert, Power and Mining Department, General Electric Co.; res., 4 Eagle St., Schenectady, N. Y.

Williams, Samuel Bortar, Cable Engineer, Bell Telephone Co.; res., 608 No. 34th St., Philadelphia, Pa.

Wilson, David H., Jr., Electrical Engineer, Erie Railroad, Meadville, Pa.

Wilson, J. F., Chief Operator, Postal Telegraph Cable Co.; res., 11 Auburndale Ave., Memphis, Tenn.

York, Bert Starr, Power Apparatus Salesman, Western Electric Co.; res., 207 Hazel Ave., Chicago, Ill.

Young, Wilbur Hubbell, Engineering Department, Gould Storage Battery Co., 351 Fifth Ave., New York City; res., Keyport, N. J.

The Secretary announced further that the following Associates were transferred to the grade of Member:

Cyrus Wellington Koiner, Secretary-Treasurer and Engineer of the National Limited and Improvement Co., St. Louis, Mo.

Carl Edward Magnusson, Professor of Electrical Engineering, University of Washington, Seattle, Washington.

L. H. Thullen, Electrical Engineer of the Union Switch and Signal Co., Edgewood Park, N. J.

Robert Francis Hayward, General Manager Mexican Light and Power Co., Ltd., Mexico, D. F.

Peter Junkersfeld, Electrical Engineer, Chicago Edison Co., Chicago, Ill.

Albert B. Herrick, Consulting Electrical Engineer, Ridgewood, N. J.

The Secretary announced further that two separate meetings would be held simultaneously this evening, as follows: in the Auditorium a meeting for the reading and discussing of a paper by Sergius P. Grace, entitled " The Telephone Wire Plant "; in Assembly Hall No. 2 on the fifth floor, a meeting for the reading and discussing of a paper by D. McFarlan Moore entitled " Light for Gaseous Conductors within Glass Tubes—The Moore Light." Manager J. J. Carty presided at the telephone meeting, Vice-president Dunn at the Moore light meeting. The papers were read by the authors. The Moore paper was discussed by Messrs. Gano Dunn, C. P. Steinmetz, P. H. Thomas, C H. Sharp, J. W. Howell, Leon Gaster, D. McF. Moore.

The Grace paper was discussed by Messrs. J. J. Carty, H. V. Hayes, G. M. Yorke, F. L. Gilman, K. B. Miller, S. P. Grace.

Annual Meeting

The 219th regular and the 24th Annual Meeting of the American Institute of Electrical Engineers was held in the Auditorium of the Engineers' Building, 33 West Thirty-ninth street, New York, Tuesday, May 21, 1907, at 7:45 p.m.

The Secretary announced that at the meeting of the Board of Directors held during the afternoon there were five Associates elected as follows:

Arnstein, Walter, Secretary and Engineer, City Electric Co. and Central California Traction Co.; res., 166 First Ave., San Francisco, Cal.

Griffith, Gerald Geoffrey, Travelling Installer of Switchboards, Western Electric Co., Chicago, Ill.; res., Kennewick, Washington.

Knapp, Lloyd Ellwood, Business Manager American Telephone Journal, 100 William St., New York City.

Muirhead, James, Assistant Designing Engineer, British Thomson Houston Co., Ltd.; res., Belgrave, Clifton Road Rugby, England.

Wilson, John Fay, Superintendent, Woodward Cotton Co., Woodward, Okla.

The Secretary announced further that the following Associates were transferred to the grade of Member:

Francis Lyman Gilman, Telephone Engineer, 463 West St., New York City.

Edwin Sibley Webster, Electrical Engineer, Stone & Webster, 84 State St., Boston, Mass.

Charles Augustus Stone, Electrical Engineer, Stone & Webster, 84 State St., Boston, Mass.

The Secretary announced further that owing to the fact that the constitutional requirement that candidates must have been posted twenty days prior to election, the 273 names listed in April Proceedings could not be acted upon at this meeting.

The Secretary then read the report of the Board of Directors for the fiscal year ending April 30, 1907. [This report is printed in full at the end of Section II of this Proceedings.]

The Secretary reported that 283 proxies had been received and that the necessary number of members were either present or represented at the meeting to form a quorum.

President Sheldon: I have had handed to me by the chairman of the Committee of Tellers, Mr. B. V. Swenson, the report of the committee on the new Constitution and upon the election of officers. I will ask the Secretary to read the report concerning the proposed revised Constitution.

The Secretary read the report showing that 2358 members voted in favor of the adoption of the revised constitution; 95 against; and 17 blank ballots.

President Sheldon: According to this report I declare the new Constitution to go into effect twenty days from this date. I will ask the Secretary to read the report of the Committee of Tellers on the election of officers.

The Secretary reported that 1406 valid ballots had been passed, of which the following gentlemen received the number stated; For President, H. G. Stott, 1312. Vice-presidents, L. A. Ferguson, 1382; J. G. White, 1376; W. C. L. Eglin, 1310. For Managers, B. G. Lamme, 1363; H. W. Buck, 1355; P. H. Thomas, 1355; Morgan Brooks, 1255. For Treasurer, George A. Hamilton, 1402. For Secretary, Ralph W. Pope, 1402. [There were a number of scattering ballots for other persons.]

President Sheldon: In accordance with this report, I declare H. G. Stott elected President to hold office for one year; L. A. Ferguson, J. G. White and W. C. L. Eglin, Vice-presidents, to hold office for two years; B. G. Lamme, H. W. Buck, P. H. Thomas, and Morgan Brooks, Managers to hold office for three years; George A. Hamilton, to hold office as Treasurer for one year; and Ralph W. Pope to hold office as Secretary for one year, to take office in accordance with the new Constitution.

A paper entitled "Some Facts and Problems Bearing on Electric Trunk-Line Operation," was then presented by Mr. Frank W. Sprague, and discussed by Messrs. W. J. Wilgus, L. B. Stillwell, W. B. Potter, C. F. Scott, N. W. Storer, G. R. Henderson, Wm McClellan, A. H. Armstrong, C. P. Steinmetz, F. J. Sprague.

Student Badges

The Board of Directors having approved a design for an emblem for the use of enrolled students, arrangements have been made to supply the following styles:

Vest-pins, scarf-pins and pendants $3.00; Buttons, $4.00

These badges are of the same shape as the standard Institute pin, but only half the size, and bear an elongated letter "S" entwined with the initials A.I.E.E. They are well made of 14K gold and black enamel. Remittance should be made with order, and if currency, the letter should be registered. If not satisfactory they may be returned at owner's risk. No engraving will be done by the Institute. It is believed that this tells the whole story, and it is hoped that letters of inquiry will not be necessary.

Code of Ethics

The report of the Committee on Code of Ethics appears on pages 779-783, Section II of this issue. It will be brought up for discussion at the Niagara Falls Convention. It should be carefully considered, and all members are invited to send in written discussions.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting.

Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before June 21, 1907.

6281 J. P. Lough, New York City.
6282 H. V. Rugg, Philadelphia, Pa.
6283 Carl Sternberg, Minneapolis, Minn.
6284 J. A. Stewart, New York City.
6285 Jan Vanderzande, San Francisco.
6286 C. A. LeQuesne, Jr., N. Y. City.
6287 C. H. Bovell, Wilkinsburg, Pa.
6288 T. D. Buckwell, Toledo, O.
6289 C. H. Felker, Toledo, O.
6290 M. W. Hansen, Toledo, O.
6291 W. H. Inbusch, Los Angeles, Cal.
6292 J. R. S. Sian, Jr., Georgetown, S.C.
6293 F. E. Congdon, New York City.
6294 H. O. Hammond, New York City.
6295 I. W. Edwards, Brooklyn, N. Y.
6296 W. A. Hyde, Washington, D. C.
6297 H. C. Tooker, New York City.
6298 F. L. Baer, Oakland, Cal.
6299 L. E. Beilstein, Toledo, O.
6300 J. O. Andrew, Great Falls, S. C.
6301 L. R. Adams, Monroe, La.
6302 A. T. Beauregard, Newark, N. J.
6303 F. J. Hoff, Brooklyn, N. Y.
6304 W. S. Kilmer, New York City.
6305 E. W. Long, East Orange, N. J.
6306 J. S. Shumaker, Boston, Mass.
6307 W.P.Van Wyck,Perth Amboy, N.J
6308 A. H. Buck, New York City.
6309 S.H. Kannacher,Schenectady,N.Y
6310 A. P. Steckel, Buffalo, N. Y.
6311 Geo. Slack, Missoula, Mont.
6312 Ray Timmerman, Provo, Utah.
6313 A. H. Berry, Lowell, Mass.
6314 F. S. Clevenger, Brooklyn, N. Y.
6315 L. Elliott, Colorado Spgs., Colo.
6316 B. C. Heldeman, Kansas City, Mo.
6317 Burnell Poole, Brooklyn, N. Y.
6318 E. B. Rannells, Brooklyn, N. Y.
6319 W. D. Scott, Buffalo, N. Y.
6320 R. H. Alton, Schenectady, N. Y.
6321 B. M. Kershner, San Francisco.

6322 C. W. Young, St. Louis, Mo.
6323 A. C. Bowen, Morristown, N. J.
6324 E. A. Baldwin, Schenectady, N. Y.
6325 A. L. DuBois, Grantwood, N. J.
6326 O. W. Lillard, San Francisco, Cal.
6327 F. J. Murmann, Mt. Vernon, N. Y.
6328 M. L. Stack, New Haven, Conn.
6329 W. A. Wagner, New York City.
6330 G. E. West, Pittsfield, Mass.
6331 D. A. Wilkes, Washington, D. C.
6332 E. J. LeBlond, Salt Lake City.
6333 C. B. Smith, Helena, Mont.
6334 W. S. Resor, Chicago, Ill.
6335 G. Lundgren, Cherokee, Ia.
6336 B. F. Simmons, Holyoke, Mass.
6337 E. L. Wilder, Pittsburg, Pa.
6338 W. A. Maxwell, Windsor, Ont.
6339 W. N. Fashbaugh, N. Y. City.
6340 W. B. Wilkinson, Chicago, Ill.
6341 F. S. Gassaway, U. Montclair.
6342 K. H. Logan, Brooklyn, N. Y.
6343 M. Creese, State College, Pa.
6344 G. R. Benjamin, Jersey City, N. J.
6345 W. F. Smith, Los Angeles, Cal.
6346 W. I. Bolen, Mexico City, Mex.
6347 M. A. Humble, Pittsburg, Pa.
6348 T. B. Mickley, New York City.
6349 W. A. Miller, New York City.
6350 G. B. Glassco, Wilkinsburg, Pa.
6351 A. B. Cox, Lynn, Mass.
6352 J. C. Terry, Chicago, Ill.
6353 J. S. Williams, Wilkinsburg, Pa.
6354 J. B. Harmon, Brooklyn, N. Y.
6355 H. C. Kendall, Wilkinsburg, Pa.
6356 C. T. Dodd, Pasadena, Cal.
6357 H. C. Gardett, Los Angeles, Cal.
6358 Daniel Maass, Pittsburg, Pa.
6359 G. D. Hawkins, Philadelphia, Pa.
6360 O. A. Fick, Boston, Mass.
6361 L. J. Heizmann, Reading, Pa.
6362 Daniel Morgan, Pittsburg, Pa.
6363 John McKenzie, Chicago, Ill.
6364 H. E. Burkart, Toledo, O.
6365 Gerald Deakin, San Francisco, Cal.
6366 J. M. Fried, Ithaca, N. Y.
6367 J. A. Johnson, Niagara Falls, N. Y.
6368 M. W. Munro, Dunedin, N. Z.
6369 A. L. Pond, Chicago, Ill.
6370 E. W. Paul, Pittsburg, Pa.
6371 R. W. Shoemaker, Farmington, Mo.
6372 M. V. Sauer, Niagara Falls, N. Y.
6373 Thurlow Travis, New York City.
6374 E. H. Bru, Pachuca, Mex.
6375 H. F. Cox, Ft. Bayard, N. M.
6376 A. G. Hastie, Wilkinsburg, Pa
6377 Charles Stephens, Wilkinsburg, Pa.
6378 G. B. Warner, Boston, Mass.
6379 J. M. Nightingale, Schenectady.
6380 O. C. Roedder, Karlsruhe, Ger.
6381 Julius Strauss, New York City.
6382 G. E. Brett, Wilkes-Barre, Pa.
6383 H. W. Deeds, San Francisco, Cal.
6384 J. T. Frankenberg, Providence.
6385 W. A. Rankin, Painesdale, Mich.
6386 C. E. Theobald, New York City.
6387 C. G. Durfee, Rochester, N. Y.
6388 A. G. Shearer, Wallsend, Eng.
6389 F. J. Baur, Holland, O.
6390 J. E. Currie, Dayton, O.
6391 A. F. Hansen, Stockton, Cal.
6392 R. M. Morganstern, Pittsburg, Pa.
6393 H. E. Aanonsen, Buffalo, N. Y.
6394 J. E. Cole, Boston, Mass.
6395 A. J. Paige, Chicago, Ill.
6396 S. H. Rogers, Brooklyn, N. Y.
6397 C. E. Brenton, St. Louis, Mo.
6398 E. B. Brown, Lynn, Mass.
6399 C. E. Colby, Windsor, Conn.
6400 H. S. Hall, Puebla, Mex.
6401 S. A. Moss, Lynn, Mass
6402 J. A. Moyer, New York City.
6403 A. P. Stephens, Danville, Va
6404 B. D. Ward, Ft. Worth, Tex.
6405 W. E. Young, Toronto, Ont.
6406 F. H. Abbott, Houghton, Mich.
6407 S. M. Greer, Brooklyn, N. Y.
6408 L. A. Shrewsbury, El Oro, Mex.
6409 W. R. Schmidley, St. Louis, Mo.
6410 V. A. Wolcott, Schenectady, N. Y.
6411 H. L. Barnholdt, Pittsfield, Mass.
6412 R. Hiltbrand, Cincinnati, O
6413 H. Milliken, New York City.
6414 J. R. MacDonald, Anaconda, Mont
6415 F. D. Newbury, Wilkinsburg, Pa.
6516 Victor Wichum, Brooklyn, N. Y.
6517 H. G. Dechant, New York City.
6418 J. M. Hipple, E. Pittsburg, Pa.
6419 M. King, Jr., New York City.
6420 A. J. Porskievies, Ampere, N. J.
6421 G. M. Simmons, Jamaica, N. Y.
6422 L. W. Nims, Mexico, Mex.
6423 O. C. Snider, Kansas City, Mo.
6424 M. Freund, New York City.
6425 Emil Grah, Toledo, O.
6426 E. H. Jewett, Toledo, O.
6427 H. T. Prendergast, Toledo, O.

6428 L. Albright, Buffalo, N. Y.
6429 W. L. Hopper, Somerville, Mass.
6430 H. F. Lincoln, Grand Falls, N. F.
6431 P. M. Rainey, New York City.
6432 C. L. Reeder, Baltimore. Md.
6433 A. R Sawyer, Lansing, Mich.
6434 R. Stearns, Schenectady, N. Y.
6435 F. D. Thompson, Brooklyn, N. Y.
6436 H. L. Darrah, Chatham, N. J.
6437 V. Durbin, Brookline, Mass.
6438 W. D. Lindsey, New York City.
6439 G. H. Malcolm, Yonkers, N. Y.
6440 G.W. Palmer, Jr., Fall River, Mass.
6441 C. D. Willison, Chicago, Ill.
6442 E. F. Davison, Rochester, N. Y.
6443 E. H. LeTourneau, New York City
6444 E. A. Löf, Chicago, Ill.
6445 J. E. Martz, Seward, Neb
6446 C. A. Newbaker, Arequipa, Peru.
6447 G. W. Thompson, Hazleton, Pa.
6448 Chas. West, Allentown, Pa.
6449 A. O'Shea, Washington, D. C.
6450 A. C. Redewill, Schenectady, N. Y.
6451 J. D. Ross, Brooklyn, N. Y.
6452 R. G. Dow, New York City.
6453 H. D. Enderiss, Philadelphia, Pa.
6454 J. T. Jennings, Pottsville, Pa.
6455 A. L. McAfee, St. Paul, Minn.
6456 J. H. Rogers, Jr., Kansas City, Mo.
6457 H. C. Brown, Salt Lake City, Utah
6458 H. B. Cleveland, Schenectady.
6459 H. Griffin, New York City.
6460 G. O. Mallett, Niagara, Falls, N. Y
6461 J. W. Sharp, Toledo, O.
6462 J. L. Diemer-Hanser, Bangkok,
6463 F. R. Fishback, Cleveland, O.
6464 C. R. R. Harris, Chicago, Ill.
6465 Paul Horan, Toledo, O.
6466 F. D. Hershberger, Chicago, Ill.
6467 A. D. Holcomb, Atlanta, Ga.
6468 H. W. Lindgren, Chicago, Ill.
6469 Lester Roth, Chicago, Ill.
6470 F. S. Davenport, Atlanta, Ga.
6471 M. D. Church, Wellsville, N. Y.
6472 H. L. Bostater, Chicago, Ill.
6473 F. H. Findley, Chicago, Ill.
6474 F. H. Gilchrest, Chicago, Ill.
6475 R. E. Hulett, Chicago, Ill.
6476 E. J. Jenness, Chicago, Ill.
6477 H. C. Mitchell, Chicago, Ill.
6478 C. M. Smith, Chicago, Ill.
6479 W. A. Stock, Chicago, Ill.
6480 W. A. Titus, Chicago, Ill.
6481 A. H. Vorum, Chicago, Ill.
6482 J. L. Walker, Chicago, Ill.
6483 F. B. Wilkerson, Chicago, Ill.
6484 Harold Binney, New York City.
6485 H. F. R. Clayton, Philadelphia, Pa
6486 L. M. Parker, Peoria, Ill.
6487 D. A. Roberts, Philadelphia, Pa.
6488 F. C. Soper, New York City.
6489 E. H. Clarke, Syracuse, N. Y.
6490 F. J. Clarke, Atlanta, Ga.
6491 H. L. Caldwell, Chicago Hgts., Ill.
6492 F. J. Hoxie, Phenix, R. I.
6493 T. M. Harvey, Columbia, S. C
6494 L. D. Layton, Syracuse, N. Y.
6495 M. W. Pullen, Onawa, Ia.
6496 J. W. Ricketts, Oroville, Cal.
6497 L. H. Burnham, Pittsfield. Mass.
6498 L. C. Norton, Toledo, O.
6499 C. B. Martin, Brooklyn, N. Y.
6500 P. S. Taylor, Los Angeles, Cal.
6501 G. H. Whitfield, Richmond, Va.
6502 H. C. Hoagland, Decatur, Ill.
6503 J. E. Felt, Toledo, O.
6504 G. J. Miller, Toledo, O.
6505 H. P. Myers, Toledo, O.
6506 T. D. Witherspoon, Toledo, O.
6507 W F. Kimball, Malden, Mass.
6508 J. B. Woodyatt, Hamilton, Ont.
Total, 228.

Applications for Transfer

Recommended for transfer by the Board of Examiners, June 7, 1907.

Any objection to these transfers should be filed at once with the Secretary.

J. F. NEWMAN, Superintendent and Chief Engineer, Wood Motor Vehicle Co., Chicago, Ill.

B. F. WOOD, Assistant Engineer, Motive Department, P.R.R., Altoona.

RICHARD MCCULLOCH, Assistant General Manager, St. Louis Transit Co.

J. L. HARPER, Chief Engineer, Niagara Falls Hydraulic Power and Mfg. Co., Niagara Falls, N. Y.

A. R. CHEYNEY, Station Supt. Philadelphia Electric Co., Philadelphia, Pa.

W. W. BLUNT, British Westinghouse E. & M. Co., London, Eng.

CALVERT TOWNLEY, 1st Vice-president, Consolidated Rwy. Co., New Haven.

A. W. K. BILLINGS, Havana, Cuba.

Annual Election

The Committee of Tellers reported to the annual meeting 1406 valid ballots, divided as follows, the names declared elected being printed in italics.

FOR PRESIDENT:

H. G. Stott	1312
C. O. Mailloux	28
J. J. Carty	16
Ralph D. Mershon	15
E. W. Rice, Jr	14
Gano Dunn	9
L. B. Stillwell	3
J. G. White	3
L. A. Ferguson	1
C. A. Terry	1
Townsend Wolcott	1
Blank	3
	1406

FOR VICE PRESIDENTS:

L. A. Ferguson	1382
J. G. White	1376
W. C. L. Eglin	1310
C. O. Mailloux	41
L. B. Stillwell	19
W. B. Potter	14
D. C. Jackson	11
H. G. Stott	10
Ralph D. Mershon	10
B. A. Behrend	9
F. A. C. Perrine	8
B. G. Lamme	3
H. M. Brinckerhoff	2
E. J. Berg	1
J. J. Carty	1
Blank	21
	4218

FOR MANAGERS:

B. G. Lamme	1363
H. W. Buck	1355
P. H. Thomas	1355
Morgan Brooks	1255
D. B. Rushmore	69
E. J. Berg	29
N. W. Storer	22
C. W. Stone	21
D. C. Jackson	19
W. I. Slichter	19
H. M. Brinckerhoff	11
F. C. Bates	9
B. A. Behrend	8
H. A. Lardner	8
Samuel Sheldon	8
H. L. Doherty	6
P. N. Nunn	5
P. Torchio	5
Wm. McClellan	3
F. N. Waterman	3
Townsend Wolcott	3
Ralph D. Mershon	2
C. A. Terry	2
J. T. Whittlesey	2
W. C. L. Eglin	1
C. O. Mailloux	1
F. A. C. Perrine	1
W. B. Potter	1
F. W. Roller	1
Blank	37
	5624

FOR TREASURER:

Geo. A. Hamilton	1402
Blank	4
	1406

FOR SECRETARY:

Ralph W. Pope	1402
Blank	4
	1406

Respectfully submitted,
B. V. SWENSON,
F. L. HUTCHINSON,
ROBERT J. LOZIER,
A. A. KNUDSON,
WM. MCCLELLAN,
Committee of Tellers.

Mining Engineers

The summer meeting of the American Institute of Mining Engineers will be held at Toronto, Ontario, beginning July 23, 1907. In addition to the usual professional sessions, there will be an excursion to the Cobalt mining region. Members of the American Institute of Electrical Engineers are cordially invited to attend. Requests for information may be addressed to the secretary of either Institute, Engineers' Building, 33 West Thirty-ninth street, New York.

Personal.

Mr. Wm. D. Shaw has gone from Telluride, Colorado, to Salt Lake City, Utah.

Mr. D. F. Huddle, Jr., has removed from Memphis, Tenn., to Schenectady, N. Y.

Mr. C. J. Welcke, of the New York operating department of the Electric Storage Battery Company, has removed his office to 100 Broadway, New York.

Mr. William Abshagen, of Allegheny, Pa., is erecting a storage battery plant for the Gould Storage Battery Company, at Carry Furnace, Rankin, Pa.

Mr. William G. Chace, formerly of Winnipeg, Manitoba, is now associated with the firm of Smith, Kerry and Chace, consulting engineers, Toronto, Can.

Mr. L. S. Thurston has left the construction department of the Cincinnati office of the General Electric Company, to take up commercial engineering in its New York office.

Mr. Geo. C. Robb, formerly coast engineer, Stanley-G. I. Electric Manufacturing Company, is now associated with the Sacramento River Supply Company, Sacramento, Cal.

Mr. Arthur M. Waitt, consulting engineer, railway specialist, has moved his office from the Whitehall building to the Reed and Barton building, at 320 Fifth avenue, New York city.

Mr. Lars R. Jorgensen, formerly with the California Gas and Electric Corporation, is now connected with F. G. Baum and Company, as designing engineer, and a member of the company.

Mr. W. K. Freudenberger has resigned his position with the National Tube Company, McKeesport, Pa., and is now electrical engineer for the Tennessee Copper Company, Copperhill, Tenn.

Mr. C. M. Janes, formerly with the Stanley G. I. Electric Company of Pittsfield, Mass., is now superintendent of electrical construction for the Juniata Hydro-Electrical Company, Huntingdon, Pa.

Mr. W. E. Foreman, formerly erecting engineer for the Westinghouse Electric and Manufacturing Company, at Pittsburg, has been appointed district engineer for the same company, at Atlanta, Ga.

Mr. Robert M. Phinney, formerly with the electrical department of the Northwestern Construction Company, Boone, Ia., is now connected with the signal department of the Illinois Central Railroad.

Mr. Fred. A. Gaby, formerly with the power construction department of the city of Winnipeg, is at present engaged on the staff of the hydro-electric power commission of Ontario, as assistant engineer.

Mr. W. H. Thompson has gone from the engineering department of the Westinghouse Electric and Manufacturing Company, at East Pittsburg, to the American Telephone Company, Wheeling, W. Va.

Mr. Raymond E. Buxton, who until recently has been connected with the Stanley G.-I. Electric Manufacturing Company, of Pittsfield, Mass., is now with the General Electric Company at Schenectady, N. Y.

Mr. Allen G. Jones has been transferred from the Schenectady works of the General Electric Company to the Lynn department, in order to become familiar with the character of material manufactured at that plant.

Mr. **John Kelley**, recently in the apprenticeship course of the Westinghouse Electric and Manufacturing Company, has been transferred to the Philadelphia district office of the company as understudy salesman.

Mr. **A. C. Lasher** of the erecting department of the Westinghouse Electric and Manufacturing Company, has been transferred from Chicago to the Atlanta district office with headquarters in the Candler Building, Atlanta, Ga.

Mr. **Fred M Lege, Jr.**, has resigned his position as engine and electrical apparatus sales engineer of the El Paso district office of the Allis-Chalmers Company, to accept the position as general manager of that company.

Mr. **T. H. Schoepf**, who has been a member of the engineering department of the British Westinghouse Company for the past five years, has resigned the position of assistant engineer, and returns to America at an early date.

Mr. **B. F. Merritt** has resigned his position as superintendent in the mechanical department of the New York Telephone Company, and is now superintendent of the Electric Goods Manufacturing Company, of Canton, Mass.

Mr. **H. A. Tibbs**, erecting engineer with the Southern Power Company, headquarters at Fort Lawn, S. C., and in charge of transmission tower line construction, has been transferred to Great Falls, S. C., as division superintendent.

Mr. **Emerson C. Tibbals**, has removed his office and factory for the manufacture of switchboards and panels from 272 Ten Eyck street, to 1201 Atlantic avenue, Brooklyn, N. Y., with greatly improved facilities for manufacturing.

Mr. **C. P. Nachod**, president of the United States Engineering Company, manufacturers of electric railway signals, announces the removal of the company's offices from 633 Bourse Building, to 929 Chestnut street, Philadelphia, Pa.

Mr. **C. E. Hardy** has been transferred by the navy department from the position formerly held by him in the navy yard at Norfolk, Va., to the position of master electrician, department of construction and repair, navy yard, Mare Island, Cal.

Mr. **E. F. Bickford**, formerly with the Pittsburg Railways Company of Pittsburg, Pa., has removed to Boston, Mass., and is associated with the Boston and Northern and Old Colony Street Railroad Company, with headquarters at 84 State street.

Mr. **Harry Barker**, formerly instructor in electrical engineering at the University of Vermont, and recently engaged in hydraulic work in White Pine County, Nevada, is now assistant editor of the *Engineering News*, 220 Broadway, New York City.

Mr. **Guy V. Williams** has resigned his position as technical advisor of the sales department for the Westinghouse Lamp Company, to become associated with Mr. John H. Bernhard, commercial engineers and sales agents, with offices in the Victoria building, St. Louis, Mo.

Mr. **C. E. Heston**, formerly stationed at Fort Hancock, N. J., as engineer in charge of fire control installation, has been promoted to district engineer, and transferred to the district of Puget Sound, to do similar work in that district, which comprises several large forts.

Mr. **J. W. White**, formerly superintendent of the American River Electrical Company, San Francisco, has been appointed superintendent of the Nevada-California Power Company, with headquarters at Goldfield, Nevada. Mr. White is also manager of the Goldfield office.

MR. CHARLES HUDSON MACHEN, for some years associated with the selling organization of the Westinghouse Electric and Manufacturing Company at the Philadelphia office, has resigned to become president of Machen and Mayer Electrical Manufacturing Company, of Philadelphia.

MR. THOS. L. MILLER, of the firm of T. L. Miller and Wilson, consulting engineers, Liverpool and Manchester, Eng., has moved to temporary offices at No. 18 Westminster Chambers, 1, Crosshall street. Liverpool, during the re-building of Tower buildings, on Water Street, Liverpool.

MR. F. S. CHAPMAN, formerly with the Cooper Hewitt Electric Company, of New York, has recently moved to Pittsburg, where he will continue work on mercury rectifiers in connection with the engineering department of the Westinghouse Electric and Manufacturing Company.

MR. SEYMOUR KNIGHT, recently chief draftsman in the electrical department of the New York Central and Hudson River Railroad, at Grand Central station, New York City, has accepted a position in the power station department of the General Electric Company, Schenectady, N. Y.

MR. L. W. BATES has left the engineering department of the National Cash Register Company, of Dayton, O., to take charge of the design and installation of additional lighting and power equipment in the power plant of the Atlantic Coast Electric Railway Company, of Asbury Park, N. J.

MR. FARLEY OSGOOD, recently General Manager and Chief Engineer of the New Milford Power Company, at New Milford, Conn., has accepted the newly created position of general superintendent of distribution, with the Public Service Corporation of New Jersey, offices at 207 Market St., Newark, N. J.

MR. L. J. CORBETT, consulting electrical engineer, and Mr. O. A. Wells, consulting civil engineer, with whom he is associated, have recently moved to 501 Empire State building, Spokane, Washington. They have just completed a gas producer plant for a light and water system for Pasco, Washington.

MR. FRANKLIN M. FARWELL, formerly in the testing department of the General Electric Company, at Schenectady, N. Y., has recently removed to Duquesne, Pa., to assist the electrical superintendent of the Duquesne Works, Carnegie Steel Co., where considerable new electrical work is being carried on.

MR. JEAN BART BALCOMB has resigned as chief engineer for the Pittsburg Filter Manufacturing Company, of Pittsburg, Pa., and is now general manager for the Hudson River Concrete Company, of New York City, doing general contracting, and making a specialty of hydraulic-electric installations.

MR. W. G. RAUCH, who has been in the service of the Southern Telephone and Telegraph Company for the past sixteen years, with headquarters at Atlanta, Ga., is now associated with Allen J. Krebs, builder of manufacturing plants, commercial and public buildings, with headquarters at Birmingham, Ala.

MR. P. LINDEMANN is now engineer in charge for the Westinghouse Electric and Manufacturing Company, at Boone, Ia., on the installation of the multiple-unit car equipment for the Ft. Dodge, Des Moines and Southern Railroad, the first steam railroad in Iowa to be electrified, which it is expected will soon be in operation.

Mr. Frank M. Ashley, M.E., has removed his offices from 138 Liberty Street, where he has been practising patent law for several years past, to the Tribune building, where he will continue to devote his time to all matters pertaining to patent law, and the procuring of patents in the United States and abroad.

Mr. J. E. Macdonald, formerly with the Pacific Electric Railway Company, has accepted a position with the Joint Pole Committee, 444 Pacific Electric building, Los Angeles, Cal. This is a recently organized committee that has assumed supervision of the joint line interests of a number of railway and power companies on the Pacific coast.

Mr. W. G. Lawrence, formerly Manager of the light and power department of Hudson, Mass., having recently completed the electrical installation of the Publishers Paper Company, at Portsmouth, N. H., has been appointed manager of the light and power department of Reading, Mass., succeeding the management of the municipal light board.

Dr. N. S. Keith, founder of the American Institute of Electrical Engineers, is now at 350 Bullitt Building, Philadelphia. He continues his business of consulting and advisory mining and metallurgical engineer. As such, he examines and reports upon mines and metallurgical processes and plans the apparatus and methods for their operation.

Mr. N. J. Wilson, who has been for many years associated with the British Westinghouse Electric and Manufacturing Company, and for some time was chief of the testing department, has taken up consulting work under the title of Messrs. Oulton and Wilson, consulting electrical engineers, State Insurance buildings, Dale street, Liverpool, England.

Mr. Andrew Pinkerton, formerly secretary-treasurer of the Power Improvement Company, Milwaukee, has opened an office at 1302 Farmers Bank building, Pittsburg, Pa., where he is engaged in practice as consulting electrical engineer. Mr. Pinkerton was for a number of years electrical engineer for the American Sheet and Tin Plate Company, at Vandergrift, Pa.

Mr. W. R. Kenan, Jr., has sold his interest in the Traders Paper Company of Lockport, and has purchased a one-half interest in the Western Block Company of that city, to the operation of which he will devote part of his time. Meantime he will carry on his engineering work in the capacity of constructing and consulting engineer for the Florida East Coast Hotel and Railway Companies.

Mr. Wm. McClellan is now associated with the Allison, Campion, McClellan Company, which has organized to engage in general engineering work, being prepared to carry a project through the periods of design, construction, and successful operation. He is located at 905 West street building, New York. This company is successor to the John W. Allison Company of Philadelphia.

Mr. Bayard W. Mendenhall has recently resigned his position as commercial engineer of the Utah Light and Railway Company, to accept the managership of the Ely Light and Power Company. Mr. Mendenhall graduated in electrical engineering from the Massachusetts Institute of Technology, with the class of 1902. For three years succeeding graduation he was connected with Stone and Webster, of Boston.

Mr. Bion J. Arnold, Past-president of the Institute, met with a painful accident at Chicago, May 5. While preparing to start his automobile, the crank was suddenly thrown back, striking him under the chin, causing the biting off of the tip of his tongue. He went immediately to the Mercy Hospital where the wound was stitched and dressed. The latest reports indicate that the wound will heal without serious results.

MR. J. H. HALLBERG, consulting engineer, is devoting part of his time to the design and manufacture of flaming arc lamps and other electrical specialties. He has moved to 30 Greenwich avenue, New York city, occupying offices with the Beck Flaming Lamp Company, also acting as engineer and general manager for that company, while still retaining his old clients, and doing a general consulting engineering business.

MESSRS. FOOTE, PIERSON & CO. have leased the building 160-162 Duane Street New York city, and have equipped their shops with a large variety of new machinery for the manufacture of telegraph instruments, fire alarm apparatus, measuring and testing instruments, X-ray machinery and electrical specialties. Their laboratories will contain the most modern apparatus for the accurate calibrating and adjusting of instruments.

MR. F. A. HALL, formerly with the Crocker-Wheeler Company, is connected with the Ingersoll-Rand Company of 11 Broadway, New York, as assistant to the chief engineer of the gas and electrical department, in special charge of the electric power work. Mr. Hall has been in the electrical engineering and manufacturing business for seventeen years, having at various times been connected with the leading companies in that line of work.

MR. C. J. HIXSON has returned to this country after spending some time abroad, and has joined the railway engineering department of the General Electric Company. He left that company in 1901 to take the position of engineer on controller and railway equipment work offered him by the Allgemeine Elektricitats Gesellschaft of Berlin. He was also identified with the experimental work in connection with the Berlin-Zossen high-speed tests.

MR. CHARLES B. BURLEIGH, one of the most earnest New England workers for the Institute, being the present Vice-chairman of the Boston Section, has been honored by the National Association of Cotton Manufacturers. At the annual meeting, April 24, the Association medal was presented to him in acknowledgement of the merits of a paper read by him before the Association at its fall meeting Sept, 13, 1906, entitled "The Curtis Vertical Steam Turbine."

MR. H. W. SAYLES, formerly electrical engineer for the Diamond Meter Company, and H. I. Waggoner, formerly with the Northwestern Electrical Equipment Company, have formed a company called the Electrical Testing Company, at Peoria, Ill., for the purpose of standardizing meters and instruments. They will also make competitive tests of meters for lighting companies. Mr. Sayles and Mr. Waggoner are both technical men and have had a number of years' experience in this class of work.

PROFESSOR ALEXANDER GRAHAM BELL has received the honorary degree of doctor of science, conferred upon him on May 2, by Oxford University, in recognition of his efforts to teach the deaf and dumb to speak, as well as for his invention of the telephone. The presentation was made by the dean of the faculty of science, Professor A. E. H. Love, and the ceremonial of conferring the degree, which was invested with the traditional solemnity, greatly impressed Professor Bell. On the same evening he attended a dinner given in his honor in London, by the Institution of Electrical Engineers.

Obituary.

MR. FREDERIC CROSSGROVE BARR, electrical engineer of the Colorado Telephone Company, died at Denver, Colo., May 9, 1907. Mr. Barr was born at Ann Arbor, Mich., May 1, 1877, and was a graduate from the University of Michigan. After six months' experience in the testing department of the General Electric Company and three months in the installation of electric coal mining machinery he was appointed electrician for the Colorado Telephone Company. Mr. Barr was elected an Associate March 27, 1903, and had since taken great interest in matters pertaining to the Institute. He was a young man of rare attainments and gave promise of a brilliant future.

MR. CHARLES K. STEARNS, for many years a prominent consulting electrical engineer, of Boston, died suddenly of acute diphtheria at the City Hospital May 13, 1907. Mr. Stearns was a son of the late Professor Stearns and was born at Newton Center, Mass., January 6, 1864. He was educated in the Newton public schools and the Massachusetts Institute of Technology. With a view of making electrical engineering his life work he entered the employ of the Thomson-Houston Electric Company at Boston, and was subsequently transferred to St. Paul. He was appointed assistant engineer in the installation of the third-rail equipment of the Nantasket Beach branch of the New York, New Haven and Hartford Railroad, which was one of the earliest examples of this type of construction. He was subsequently engaged in electro-hydraulic development as well as railway work. His standing as a citizen and engineer was of the highest. Mr. Stearns was elected an Associate August 6, 1889, and transferred to the grade of Member May 16, 1893. He was also a Member of the American Society of Mechanical Engineers.

MR. WM. J. JOHNSTON, a pioneer electrical editor, and founder of the *Electrical World*, died suddenly from cerebral hemorrhage, on April 28, 1907. He had been in good health, and was exceptionally well-preserved for a man of his age. He was born in Ireland in 1851, and after learning Morse telegraphy he became a permanent resident of this country nearly forty years ago. He was an early contributor to *The Operator*, founded in 1874, and eventually its owner. It was established in the interest of telegraphers, and under his management it became a journal of high standing, considering its rather limited field, and the meager development of the electrical art at that period. Mr. Johnston's progressive spirit was evident in his efforts to keep abreast of the growth of the industry. No doubt it was apparent to him that his readers failed to appreciate the great changes that were taking place, and while endeavoring to hold them in line, he established the *Electrical World*, with which he merged *The Operator*. The final success of this enterprise is well known. It was due to intelligent and arduous work, persistent effort under extremely adverse conditions, but with ever growing confidence in the future. In 1899 Mr. Johnston sold this valuable property to its present proprietors, and subsequently entered the field of mining journalism, continuing until 1906. Meanwhile he had purchased an interest in the *American Exporter*, and was active in its management during the brief remainder of his life. Mr. Johnston was a charter member of the Institute; and as its first secretary (Dr. N. S. Keith) was employed upon the editorial staff of the *Electrical World*, the first volume of the TRANSACTIONS was issued from the office of that journal, then at No. 9 Murray Street. Through his sympathetic efforts for the advancement of the electrical engineering profession, he wrought for himself an honored position in the history of the art, and his memory will be entwined with the printed records of achievement which will be handed down to future generations.

Officers and Board of Directors, 1906-1907.

PRESIDENT.

Term expires 1907
SAMUEL SHELDON, Brooklyn, N. Y.

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Baltimore.........Dec. 16, '04	J. B. Whitehead.	C. G. Edwards.	2d Friday.
Boston............Feb. 13, '03	H. E. Clifford.	C. H. Porter.	3d Wednesday
Chicago.................1893	P. B. Woodworth.	H. R. King.	1st Tuesday after N. Y. meeting.
Cincinnati.........Dec. 17, '02	C. S. Reno.	L. Lowenberg.	
Columbus.........Dec. 20, '03	R. J. Feather.	H. L. Bachman.	1st Monday.
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Philadelphia.......Feb. 18, '03	W. C. L. Eglin.	H. F. Sanville.	2d Monday.
San Francisco......Dec. 23, '04	C. L. Cory.	A. H. Babcock.	
Schenectady.......Jan. 26, '03	D. B. Rushmore.	E. E F. Creighton.	2d Wednesday.
Seattle............Jan. 19, '04	C. E. Magnusson.	W. S. Wheeler.	3d Saturday.
St. Louis..........Jan. 14, '03	A. S. Langsdorf.	J. H. Finney.	2d Wednesday.
Toledo............ June 3, 07	W. G. Nagel.	Geo. E. Kirk.	
Toronto..........Sept. 30, '03	R. G. Black.	L. W. Pratt.	2d Friday.
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Cornell University..Oct. 15, '02	E. L. Nichols.	H. H. Norris.	1st Friday after N. Y. meeting.
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Purdue University..Jan. 26, '03	C. P. Matthews.	J. W. Esterline.	Every Tuesday.
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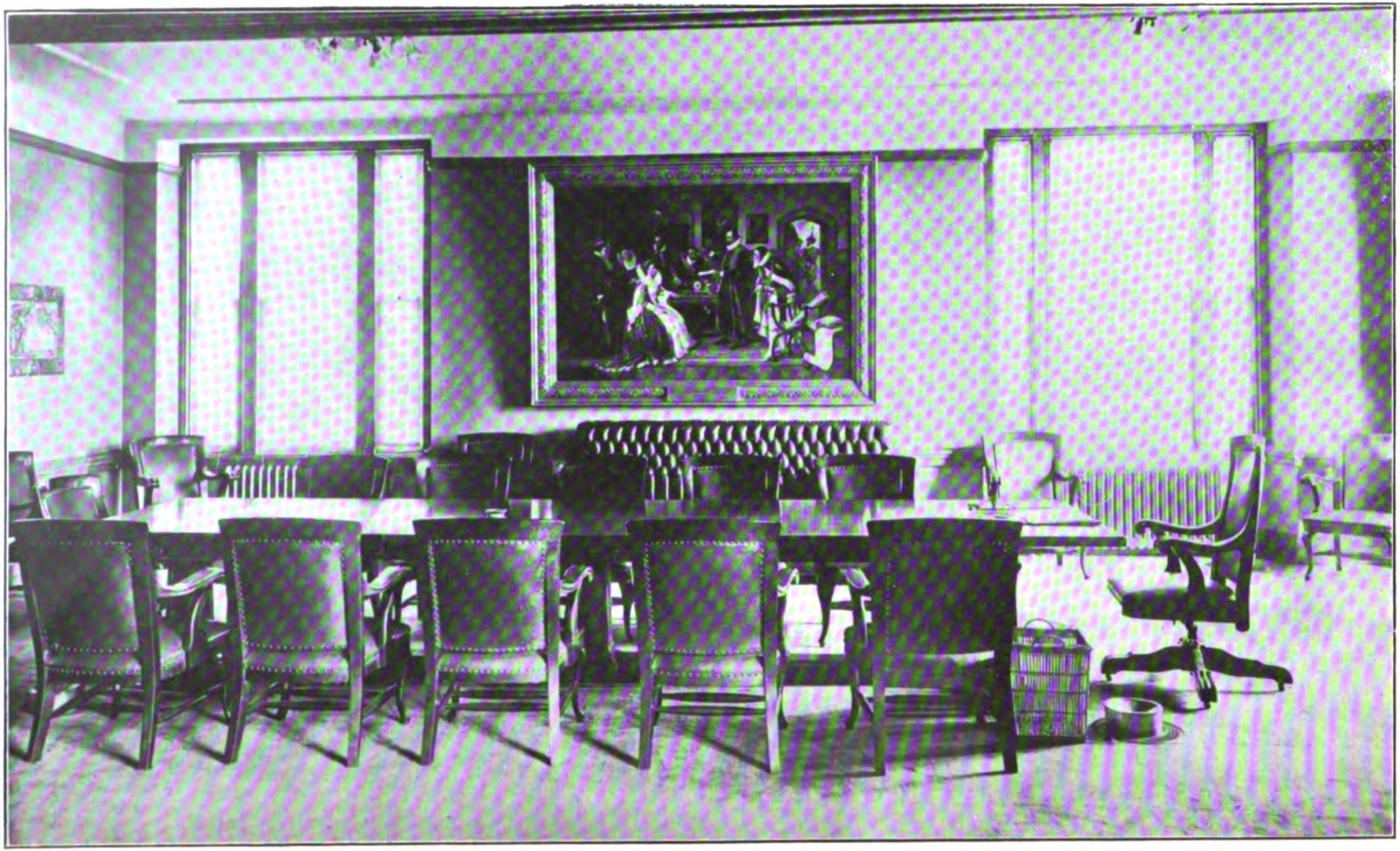

Board of Directors' Room, A. I. E. E., showing Painting of Dr. Gilberd Exhibiting his Electrical Experiments to Queen Elizabeth and her Court. Presented by **the Institution of Electrical Engineers** (of Great Britain) at St. Louis, September, 1904.

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

Published monthly at 33 W. 39th St., New York City, under the supervision of

THE EDITING COMMITTEE,
THOS. J. JOHNSTON, Chairman.
GANO DUNN. CECIL P. POOLE.

RALPH W. POPE, Editor.

Subscription. United States, Mexico and Cuba, $5 per year.
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Single copy 50 cents.
Subscriptions must begin with January issue.

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Space.	**Less than half year.** per issue.	**Half year.** per issue.	**One year.** per issue.
1 page	$36.00	$32.00	$30.00
½ page	22.00	18.00	16.00

Additional charges for Preferred Positions.
Professional Cards, special rate of $25 per year.

Vol. XXVI. **June, 1907.** No. 6.

The Peak Load

ONE of the burning questions of central station operation is the equalization of the day and night load. A similar problem exists in various manufacturing and business concerns, with this difference, however, that instead of a day and night period, it is the change of seasons which is to be considered. Those who are familar with Institute work realize that its apparent period of activity is between September and the annual convention. This is quite true; but meanwhile certain work has necessarily been laid aside because of the pressing importance of providing for meetings, each of which brings its unfailing quota of preparation, and is immediately followed by a train of events which fills the gap **until** the next date. Outside of stenography and typewriting, a staff trained in Institute work cannot be immediately supplemented in case of an emergency.

Nearly every civilized organization has a vacation season, which in the case of the Institute begins immediately after the annual convention. All through the winter the papers and discussions which have been put in type are again proofread and then electrotyped. The scattered contributions from various parts of the world are grouped as far as possible with the papers to which they pertain; the final work of re-paging is begun, and the printing started. Many members evidently labor under the impression that this should be done on the second day of January, and because it is not that an inquiry should be made as to when the TRANSACTIONS will be delivered.

In 1888 the Institute began the publication of its PROCEEDINGS in monthly parts in order that members might keep in touch with its work throughout the year. The practical duplication of this printing in the form of a volume of TRANSACTIONS was found desirable, and this is now the recognized practice of the other three national engineering organizations. The final preparation and distribution of this volume follows the peak load of the yearly operations of the Institute, and when the summer vacations are over, if each member has meanwhile paid his dues, and furnished his latest address, he will find his TRANSACTIONS awaiting him upon the resumption of his duties. Theoretically, all this should have been done earlier in the year; but it does not appear possible without seriously interfering with regular work during the busy season.

Sections and University Branches

IN accordance with Article IX, Sections 65–74 of the new Constitution, the local organizations heretofore known as Branches, may, by petitioning, be admitted as Sections of the Institute. By way of simplifying matters, the terms University Branches and Student Meetings will be merged; both of these Sub-sections will hereafter be known as University Branches. In brief, there will be but two kinds of local organizations—Sections and University Branches. A Section may be restricted to a town, or its activities may extend over all the adjacent territory for which the town is a natural electrical center. These details will be modified here and there by local conditions, the final decision resting with the Sections' Committee and the Board of Directors. The jurisdiction of a University Branch is, in general, confined immediately to the university or college whose name it bears. In order that these jurisdictions may be clearly understood, it is the intention of the Sections' Committee to publish in a future issue of the PROCEEDINGS an outline map of North America showing the geographical jurisdiction of every Section and University Branch. With the closing of the universities and colleges for the academic year 1906–1907, and the beginning of the heated term, the Sections and University Branches will, as usual, suspend active operations until the autumn of 1907. Section and University Branch activity will be renewed immediately after the first regular meeting of the Institute in New York on the second Friday of October, and the reports of meetings will again be bulletined in the PROCEEDINGS.

After Graduation

AT this season graduates of every description are being overloaded with good advice, which even if appreciated at the moment may soon be forgotten. It is rarely acted upon. A very small proportion of electrical engineering graduates are enrolled as Students of the Institute. Many of these have applied just before graduation, and hope to enjoy the benefits of this attachment for a period of three years. During this time they should be able to determine whether they are really qualified to remain permanently in the profession. The question will naturally arise whether it is worth while to apply for election as an Associate, and if so whether they can afford to pay the dues.

By referring to the list of past-presidents of the Institute, the names of many well-known leaders in the electrical profession will be found. If these men have found membership in the Institute advantageous, why should it not be advisable for the young electrical engineer to follow their example? The past-presidents are referred to here, because many of them have permitted their work to be made public through the channels of the Institute. The Institute, through their efforts, supplemented by those of hundreds of others who have devoted time, energy, and money to its welfare, is now in a position to be of greater benefit to the electrical industry than at any previous time in its history. In twenty-five years the graduate of to-day will consider his date of election as an Associate a valuable asset. Members who through financial embarrassment were compelled to resign many years ago, occasionally apply for reinstatement and pay their accumulated dues, frequently amounting to a considerable sum, in order to retain their original dates of election and transfer. Meanwhile they have prospered, and do not really require the benefits of Institute membership so urgently as the young engineer whose spurs are not yet won. Do not make the old and well worn excuse that it is impossible to attend the meetings; neither can the residents of Japan, New Zealand, India, or Australia. Those distant countries are, however, well represented on the Institute list, and many of them have shown their appreciation of their affiliation by subscribing to the building fund, although they may never visit America. Many professors in their parting word to graduates, advise them to join the Institute; and they are certainly qualified to speak of its value in continuing the education which accompanies practical experience throughout the life of each individual.

The European Tour of the American Institute of Electrical Engineers During the Summer of 1906 *

BY C. T. WILKINSON.

Though the time at our disposal will not permit a detailed consideration of all the points of interest in connection with this tour, it is hoped that by touching briefly on the things of greatest importance some idea may be conveyed of the progress in the electrical art made by European electrical engineers.

The special interest now being taken both in America and Europe in the problems connected with the development and transmission of electric power, seems to call for special reference to this subject.

Part 1. Italy and Italian courtesies. It is unfortunate that circumstances arose which prevented the American Institute of Electrical Engineers from formally accepting the courteous invitation of the Italian Society to visit the Milan Exhibition on their way to the International gathering arranged to meet in London on June 23, 1906, as a visit of very great interest was thereby sacrificed.

Among the faithful few who decided to adhere to the previously considered program of the Institute were, Past-president J. W. Lieb, Jr., and Mrs. Lieb; Prof. Harrison W. Smith of the Mass. Institute of Technology; Prof. Morgan Brooks and son Henry Brooks, and Captain C. M. Mitchell of Niagara Falls.

Disappointed, however, in the number of their guests, our Italian colleagues succeeded in showering their hospitality on those who appeared, and were especially pleased with the opportunity offered to entertain their old friend John W. Lieb, Jr. Their indefatigable secretary, Sig. Guido Semenza, has left many impressions of gratitude with those few who daily made his office a meeting place, where he frequently tendered his services as interpreter and acted in general as guide, philosopher, and friend to our small party.

THE MILAN EXHIBITION

In considering the Milan Exhibition from the electrotechnical point of view, it must be remembered that it was an exhibition chiefly of traction, transmission, and manufacture, with additional sections offering valuable prizes for fire-brigade work, navigable balloons, or flying machines. No special section was set aside for electrical work, which had to be looked for as part of exhibits under more general heads, or else in kiosks separately erected by the electrical manufacturers, usually to be found in or near the machinery hall in the center of the Piazza d' Armi.

Electrotechnically, the traction exhibit was undoubtedly the largest, as was to be expected when we recall that the Milan Exhibition was to commemorate the opening of the Simplon tunnel.

Though the exhibition was large and interesting to the average visitor, the things of great novelty in the electrical engineering side were not very numerous, the most important being the single-phase Finzi railroad, which connected the two halves of the Exhibition, Piazza del Marco and the Piazza d' Armi, separated by a distance of about one mile. No special section being provided for electrical work, considerable time was lost. Thus the switchboard exhibit of Messrs. Brown-Boveri was to be found in the hygiene building, the stand of a prominent electrical manufacturing concern of Belfort was situated in the neighborhood of the instrument building, while Messrs. Richard-Ginori and Messrs. Pirelli had kiosks near the machinery building in

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Abstract of lecture before the Pittsfield Section, January 3, 1907.

*For many slides showing Italian subjects and the social side of the English tour the writer is indebted to Professor Harrison W. Smith of the Massachusetts Institute of Technology, Boston, whose photographic record of the tour is delightfully complete.

the center of the Piazza d' Armi. On the whole, therefore, while the Milan Exhibition was of interest to the American and European electrotechnical world, its interest centered on isolated exhibits, and showed that:

1. Certain firms in Italy are ahead of the best work of other countries in some branches of manufacture.

2. There is a large class of manufacturers who, while making comparatively large exhibits, merely show skill in adapting ideas culled from America and England, and especially from the St. Louis Exposition.

The Milan Exhibition is a sign of the times in Italy. The new title of "chevalier," given to those who have done notable work in manufacture—a degree that ranks very highly among bestowed honors—will undoubtedly tend to promote manufactures in Northern Italy, while the opening of the Simplon tunnel will facilitate trade relations with other European countries.

The energy and keenness of the northern Italian is illustrated by the long hours of work and the widely expressed determination to force his country to a position of leadership.

The electrical features of the Milan exhibition. The progress in high-tension work was well represented by the 100,000-volt cable manufactured by Messrs. Pirelli. This firm, it will be remembered, supplied the high-tension cables for the Ontario Power Company of Niagara Falls. This cable was carefully graded with regard to its specific inductive capacity in accordance with the theory developed by Mr. O'Gorman of the Institution of Electrical Engineers.

The stranded conductor (which is 162 sq. mm. in cross-section) is covered with a lead sheath producing a smooth surface of much greater radius, by which device alone the static strain is considered to be reduced more than 20%. The total thickness of insulation is $\frac{5}{8}$ in and the over-all diameter $2\frac{5}{16}$ in.

The extremely small insulation dimensions of this cable are very remarkable, since probably with an ungraded cable wrapped with the same thickness of insulation the rated pressure would be less than 50,000 volts.

This cable was recently tested for break-down point at the engineering congress held at the conclusion of the exhibition, and three samples tested in five- to six-meter lengths broke down at 208,000, 202,000 and 210,000 volts respectively.

The Semenza type insulator. In the Semenza insulator the wire is fastened below the upper petticoat. It is, therefore, not necessary for this petticoat to be strong enough to resist perforation. It need only be water-tight and sufficiently hard to resist mechanical shocks and rough usage in transportation. It is, therefore, made of a cheap form of terra-cotta.

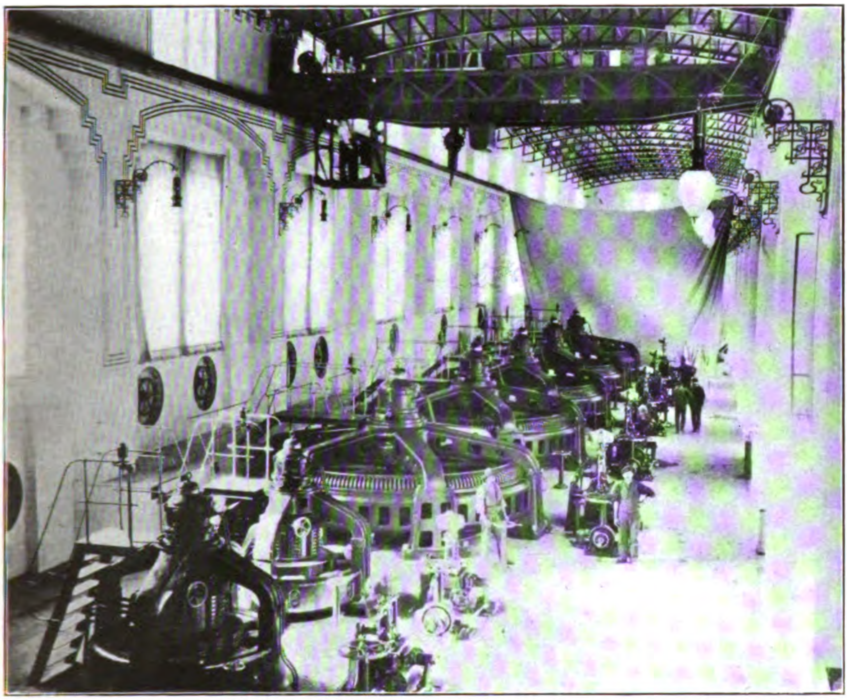
The point of attachment being somewhat lower than in the old type, the strain-moment is reduced, thus enabling a reduction to be made in the thickness of the insulator and in the diameter and cost of the iron bolt. Since this upper petticoat or umbrella is not connected in any way with the pin, complications due to increased capacity are claimed to be avoided. The saving in price between the Semenza insulator and one of the old type is stated to be between 30 and 40% for an equally safe installation for working pressures between 35,000 and 50,000 volts; for working pressures of 80,000 to 90,000, a saving of 50%, is claimed. The drops of water that collect on the surface of the insulator seem to indicate that these good results are not affected by heavy films of moisture.

Sig. Semenza says he considers one of the reasons for the remarkable results obtained in test to be that the wire is at no point in touch with a stream of water running over the surface of one of the effective petticoats of the insulator. It might perhaps be said that the important feature of the insulator seems to be that the live wire and the effective surface of the upper petticoat are screened from "live water."

It is interesting to note that tests indicate that the break-down point under the heaviest rainstorms is only in the neighborhood of 90% of the dry-weather break-down.

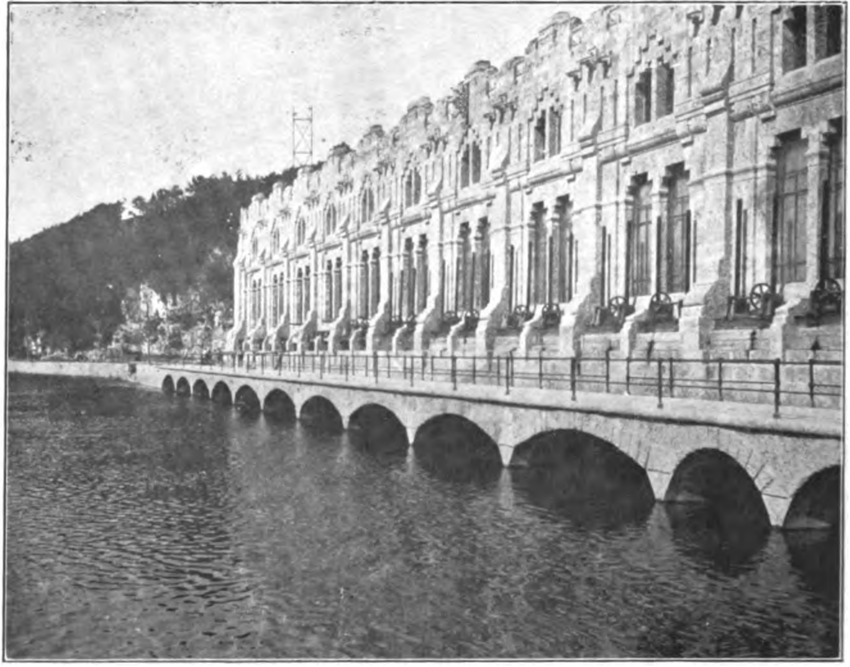
The Finzi single-phase road. The remarkable work by that pioneer and leader of Italian engineers, Dr. George Finzi, has recently attracted considerable attention, especially through the fact that he has just completed a large factory (covering twenty acres of ground) for the development of single-phase traction apparatus in conjunction with the Société Westinghouse de Paris. Under this agreement both companies will push their combined patents. For high-speed experimental trials, a circular track has been built surrounding the factory.

The line operates at a frequency of 15 cycles; the choice of this low frequency is considered essential to its success. In addition, a vital feature is the method of neutralizing the armature reaction by means of a subsidiary coil in series with the armature, and placed at an angle of 90 degrees with respect to the field-magnet coils. This method of neutralizing the armature reaction is also employed by Messrs. Brown-Boveri, among the most successful builders of direct-current turbo-generators in Europe, and whose shops contain in process of construction several direct-current machines in sizes up to 2,000 kw.



Interior of the Hydroelectric station at Trezzo near Milan, Italy
(Italian material and workmanship)

The diagram of the train circuits for motive power is of considerable interest. The system is easily controlled from either end of the train, the transformer being divided into two parts—one in the front carriage and the other in the last. The current is collected at 2,000 volts, and passing through the choke-coil of the lightning-arrester enters the relay of the main switch, which can be operated automatically or by hand. From the relay it passes through the switch, main fuse, primary of the transformer in the first carriage, along the train by one of the three wires placed on the roof, and enters the primary of the second transformer at the other end of the train, and finally returns along the track to the generating station.



The Trezzo Hydroelectric power station near Milan, Italy
(Italian material and workmanship)

The third high-tension line just referred to is used for placing the primary of the first transformer in parallel with the main switches.

The complete equipment of the train consists of six motors, two on each of the end or driving cars and one on each of the intermediate or passenger cars, the motors being arranged in groups of three for each transformer.

The first position of the controller gives approximately half normal voltage, and the following controller steps from one to seven after the first application of half normal voltage adds 30 volts each to the secondary, bringing the motor voltage from 180 to 360, which with three in series gives the average value of 120 volts per motor. The reversal of the motors is obtained in the same way as in the direct-current system.

The brushes are made as long and narrow as possible, and a large number of commutator segments are employed, but no resistance is interposed between the winding and the segments.

The acceleration of the motors at starting is stated to be 0.5 ft. per second per second. The operation of the motor is apparently extremely satisfactory, the commutation being very good.

An interesting feature of the Exhibition was the installation of the trackless trolley system, a sytem invented by Ing. Frigerio of Milan, and which has already been installed in numerous towns in Italy, serving to connect the cities with the country districts.

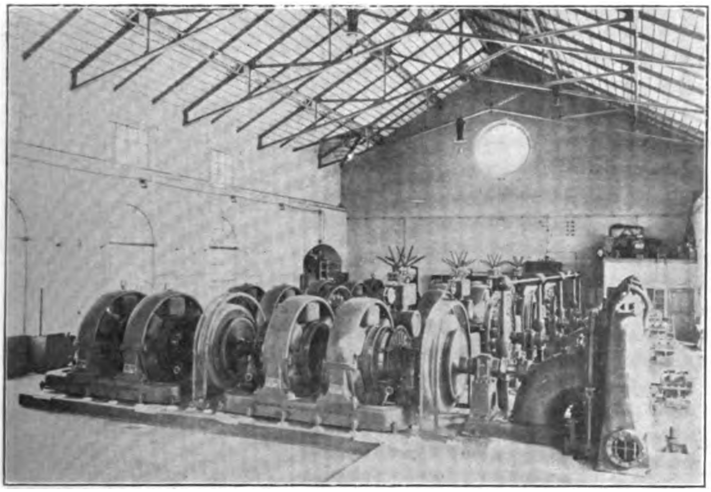
In this system both positive and negative conductors run overhead and a four-wheel collector is employed—two wheels on each wire. The current enters through the trolley arm, passes through the controller into the motor (which is geared directly to the wheels of an omnibus), and returns by the trolley arm to the overhead conductor. These vehicles are mounted on springs and provided with solid-rubber tires. Since the roads in the Reviera district are in general very good, speeds up to 20 miles an hour are reached.

The mounting of the trolley arm is so arranged, and the arm itself is of sufficient length, to enable the omnibus to move from side to side over a distance greater than its own width, thus offering great facilities for the negotiation of such traffic as is met with.

Transmission problem in Northern Italy. The present status of transmission line work in Italy is of great interest. There is a dense network of transmission lines surrounding the city of Milan.

A map was prepared especially for the balloon and airship trials in connection with the Exhibition in order that the grappling irons used by the aeronauts might not be permitted to foul any high-tension lines. This map also served to illustrate the rapid growth of transmission in Italy.

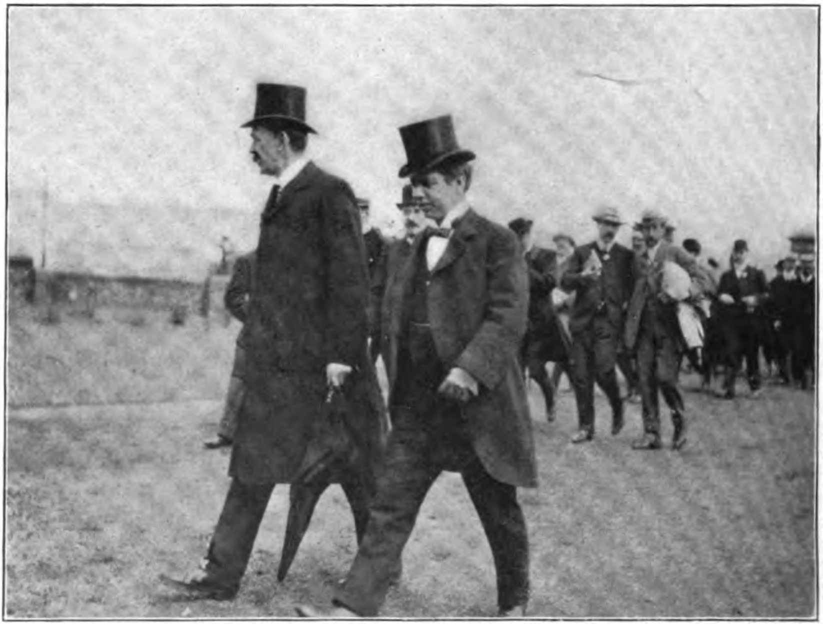
The latest station in the Milan district is that at Trezzo. It is equipped entirely with Italian material and built by Italian labor. The picture of the interior is taken from the switchboard which is situated at one end of the station. The water-wheel governors shown in the foreground are noteworthy from their extreme simplicity of construction and the admirable results obtained in service. The



The Interior of the 60,000-volt direct-current hydroelectric station at Moutier (Savoy) (Thury patents) This station transmits power to Lyon, France, 115 miles waterfall is very low, not more than 25 feet. The transmission tower used on this system illustrates the latest development of this work. It was designed by Sig. Semenza. A point of interest is the arrangement of the equilateral triangle formed by the points of support, which it will be noted does not have its base-line parallel to the horizon, but is tilted in a mathematically correct position to give the greatest permissible swinging of the wires without contact.

The Ligurian Hydroelectric Company is one of the most prominent of the companies now rapidly springing up in all parts of northern Italy, having as their object the development and conversion of water power and its transmission to factories, central stations, and railways. The leading engineering spirit is Professor Zunini of the University of Milan, and the scheme is backed by thoroughly trustworthy financial men.

In this connection it should be noted that in Italy coal is very expensive, ranging from $7.00 to $9.00 per ton, and that finding herself almost entirely dependent on water for any economical attempts of power production, Italy has recently devoted much attention to the cheapening of that most expensive adjunct, hydraulic engineering.



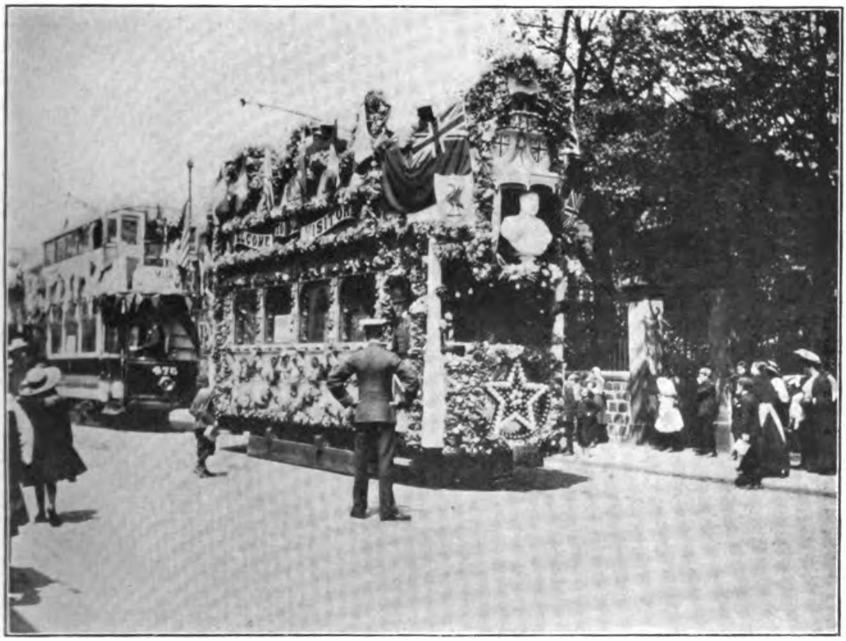
The Party in Liverpool—In foreground Schuyler Skaats Wheeler, president of the American Institute of Electrical Engineers, and Dr. R. T. Glazebrook, F. R. S., president-elect of the Institution of Electrical Engineers

The capacity of the various plants is as follows: Bormida, 7,000 h.p., situated 34 miles west of Genoa. Orba inferior, 6,000 h.p., having a power station at Molare, 27 miles from Genoa to the northwest. Orba superior, 16,000 h.p., 10 miles to the west of Genoa. Aveto, 54,000 h.p., having a main power station at Cicagna, 21 miles east of Genoa. Enza or Isola plant, situated 27 miles to the north of Spezia, on the Mediterranean Sea.

The Aveto River flows into the Po and has its source near Cabanne, where a lake will be formed with a capacity of 54,000,000 cu. m. by erecting a dam 44 m. high at the northeastern end. A storage reservoir will catch the flood water and provide for a continuous flow down the old water course double the present observed minimum. The capacity of this reservoir will be 10,000,000 cu. m. From the main reservoir at Cabanne a water course five miles long is being constructed, one-half of which will be ditched and the other half tunneled. From this channel a continuous flow of 2.5 cubic metres per second as a minimum quantity may be drawn with a peak-load allowance of 7 cubic metres per second.

The various waterflows considered throughout the whole system have been checked by examination of meteorological observations extending over the last 70 years, and by more close personal study by the society's staff since 1903.

The head of water dealt with is so great that it has been divided among three stations, the first two to be used by the society, and the power from the third station to be given to the railway administration of Italy, in accordance with Italian law, if claimed by them within ten years of the granting of the rights.



In Liverpool—The decorated tram cars which conveyed the party through the city

The first generating station has a water head of 1,148 ft. and will have 8 units of 3,200 h.p. each installed. The second generating station will have a head of 623 ft. and a final output of 16,000 h.p. divided among five generating units. The third station, the development of which is left to the railway administration, will have a head of 557 ft. and total output of 12,000 h.p.

It is estimated that the total amount of energy from the first and second stations will be 60,000,000 kw-hr. per annum, and from the third station 20,000,000 kw-hr. per annum. The cost of the first and second stations is estimated at 16,000,000 francs, and it is estimated that power may be sold to the average customer for five cents per kilowatt-hour.

The Enza or Isola project has a capital of 2,500,000 francs, to be raised to 4,000,000 francs, and the hydraulic and civil engineering has already begun. It takes water from the Enza River where a reservoir of 4,000,000 cu. m. is being built.

An earth dam 20 m. high will form the barrier thrown across the river. This is a daring piece of civil engineering, and if successful will lead to a great cheapening of future hydraulic work in Europe. The water from this reservoir is taken by a water course three miles long to the Rimagna or first station, producing a fall of 120 ft. with 4 cu. m. per second, corresponding to 1,600 h.p.

The transmission lines on these systems will operate at 33,000 volts and probably 42.5 cycles per second. The other power schemes which are being undertaken by this society are very similar in plan to those above described

THE ENGLISH TOUR.

Although of great interest from an engineering point of view, the English visit, both during the international gathering in London from June 23 to June 28, and the tour through the provinces from June 28 to July 7 1906, will probably leave a more lasting impression on the American visitors from its social aspects.

The reception and the entire plans were marked throughout by the utmost cordiality, and, in the magnificent and extensive preparations made every-

Boarding the decorated cars in Liverpool—President John Gavey, C. B., of the Institution of Electrical Engineers, and Mrs. Gavey, in foreground where for the reception of the visitors, there was evidenced not only the hospitality of a great nation, but the desire to outdo the kindness shown to the British society in its previous visits to other countries, a desire which was undoubtedly fulfilled.

The reception in London included the ceremony of the opening of the National Physical Laboratory by the Secretary of State for War, a dinner at the Hotel Cecil on the opening day at which over 500 guests were present, including Lord Kelvin, Lord Suffield, Sir William White, Sir Alexander Binnie, Sir William Ramsey, Sir Henry Vance, Sir Charles Owen, Sir W. Crookes, government officials, the consuls of the countries sending delegates, the presidents and secretaries of the visiting institutions, and a large number of distinguished visitors.

A street scene in Liverpool—The party boarding the decorated cars—Sig. Guido Semenza in foreground

The reception at the Natural History Museum, luncheon parties, visits to works, power stations, etc., sight seeing excursions in the city and to Windsor, made a perfect round of enjoyment, throughout which the elaborate care and forethought of our hosts showed in the smoothness of all arrangements.

The tour through the Provinces. The number who actually responded to the invitation of the Institution of Electrical Engineers for the tour through the provinces, was as follows:

Germans	71
Italians	41
French	17
Swiss	14
Americans	14

The remainder, bringing the total up to over 200, were British.

The provincial tour was marked by similar tokens of cordiality and kindness.

At all the cities visited, receptions and banquets were the order of the day, these taking place at the invitation of the lord mayors, lord provosts, and city officials.

Perhaps the keenest interest focused on the gathering which assembled at the University of Glasgow on Monday, July 2, by invitation of Lord Kelvin, where the reception took place in the famous Bute Hall. Several interesting incidents occurred, among them the presentation to Lord Kelvin by the Associazione Electtrotecnica Italiana of two magnificent reproductions of old drawings of mathematical and mechanical subjects by the versatile Leonardo da Vinci.

Part 2.—The provincial tour. The chief features of engineering importance in the Engish tour were:

1. The development of steam turbine work,
2. The lighting developments,
3. The growing popularity of concatenated motor converters.

Messrs. Willans and Robinson had a large number of turbines under construction, the chief of which were several 3,000-kw. sets operating at 750 rev. per min., 180 lb. pressure and 100 degrees superheat. These sets which represent the latest practice of this company, employ definite ventilation of the generators. For the bearings, oil under pressure is supplied to the center and carried along the surface of one longitudinal groove. The by-pass is arranged for automatic operation

In the garden of the Prince of Wales Hotel in Ambleside (Lake District) July 1. Mons. Paul Dapple, manager of the "Compagnie de l'Industrie Electrique et Mecanique" of Geneva, and Professor Andrew Jamieson of Glasgow from the governor when the throttle is fully opened. The casing is built up in several pieces and the high-pressure end mounted on a machine surface which allows sufficient motion to take care of the expansion due to change in temperature. The balance pipes are taken out from an intermediate stage and run separately through an expansion-joint to the balance-rings, no longer forming part of the main casing as in former machines. It is of interest to note that vibration tachometers are used throughout their testing department.

Another prominent English manufacturing concern recently built a 750 kw. machine operating at 1600 revolutions per minute and direct-connected to a direct-current generator operating at 400 to 550 volts. The field winding of the generator is so arranged that the machine will operate as a lighting generator, shunt wound, or as a traction generator, compound wound. The rating is 1670 to 1870 amperes at 400 to 450 volts shunt wound and from zero to 1360 amperes at 500 to 550 volts.

The auxiliary or commutating poles belong to an entirely distinct magnetic system with a separate yoke. This yoke is made up of two rings rather less in diameter than the main yoke and the commutating poles (which have the same length along the axis of the machines as the main poles and are laminated) project into the spaces between the main poles. They are excited by a winding in series with the armature and so designed as to give a field of the correct strength for commutation. The commutation magnetic system is not saturated and the flux is, therefore, practically proportional to the load.

A diverter is provided in parallel with this winding, by means of which

A Sunday in the Lake District—The start from Windermere, July 1, '06 for the coach ride to Keswick the proportion of the main current flowing around the commutation poles can be shunted. This diverter also serves to render the change of flux in the commutation magnetic system extremely rapid, acting on the well-known principle of a large inductance shunting a smaller one.

This diverter stands beside the turbo-generator. It is about 3 ft. in height and similar in construction to a standard core-type transformer, being provided on the top with an adjustable air-gap for varying the inductance, and in front with a large copper revolving switch with several studs which serve to vary the number of turns, the studs being connected to taps in the winding.

The commutator which is approximately 3 ft. long has five shrink-rings. Carbon brushes are used and ebonite protection pieces are fixed in the spaces between the revolving shrink-rings.

The turbo-generator sets by Messrs Parsons of Newcastle-on-Tyne, present many interesting features, and the following points will serve to illustrate their latest design. Probably the most important of the recent improvements in this type of turbine is the adoption of the unstrippable blading. This type of blading is also used by the Brown-Boveri company of Switzerland.

The blades are very similar to the old form previously used, being placed around the drum in a recessed groove, each one separated from its neighbor by a distance-piece, and a metal supporting ring is recessed and brazed into the side of each blade at a distance of approximately $\frac{1}{4}$ in. from the top. The top, $\frac{1}{8}$ in. is, however, cut as thin as paper. This is considered strong enough for the small pressure to be carried by each blade. In case rubbing occurs between the top of the blade and the surrounding cylinder, the former

In the Lake District, Leaving Grasmere, July 1, '03.

will not break, but will simply burr over. Another feature of interest is the employment of the closed-slot construction for the stators of the Parsons alternators. This company considers that the extra labor involved by the consequent hand winding of the armature is more than counterbalanced by the resulting possibility of making a solid (unlaminated) metal rotor, and the much improved wave-form obtained. Further, the increased self-induction is not considered a disadvantage; since it tends to limit the short-circuit current and thus reduce the severe mechanical strains to which a short-circuited turbo-generator is subjected.

Definite ventilation as now employed throughout by German and Swiss firms, is not yet the regular practice of the Parsons company, but is beginning to be asked for somewhat frequently.

Lighting situation. Tantalum, osmium, tungsten, zirconium, wolfram, bastian mercury vapor type, and several patterns of flame arc lamps are only a few of those now to be seen in many parts of Europe, while almost every engineer to be met with has a friend with a new lamp idea which is to sell for next to nothing, and have a wonderful life and efficiency.

It is, however, certain that in Europe the carbon-filament lamp is rapidly disappearing. The tantalum lamp sells for about 60 cents. The zirconium is promised for about 30 cents. The bastian lamp with its 10,000-hour life and 0.8 watts per candle power consumption, sells in the neighborhood of $10.00, but there is great possibility of this price being shortly reduced. Flame arcs are to be seen everywhere, and the conditions are

In the Lake District July 1—Mr. W. M. Mordey and party leaving Grasmere such that financial men hesitate to invest money when the next day may find their lamp superseded.

Part 2.—Machines for converting from alternating to direct current. A greater variety of these machines is to be seen in Europe than in the States. Those at present in use of more especial interest to Americans are the permutator and the motor converter. The permutator is manufactured by the Societa Egyptiene d' Electricite of Paris. These machines are being called for more frequently than in the past.

A 50-kw. 600-volt direct-current, 2000-volt alternating-current, three-phase permutator was exhibited at the Milan Exhibition intended for operation in multiple with a motor-generator set and it was claimed that it would give satisfaction, but the construction of this plant was not completed at the time of our visit.

The motor converter manufactured by Bruce-Peebles Company of Edinburg has recently made great progress in England, manufacturers claiming to have a total kilowatt capacity manufactured and in hand greatly exceeding all the synchronous converter kilowatt capacity in the country.

The field of this type of converting apparatus lies in high-frequency, moderately high alternating-current voltage (not exceeding 13,200 volts approximately) and a high direct-current voltage. Under these conditions very favorable cost comparisons are obtained with any other converting apparatus; a slight saving in floor space and a somewhat wide voltage variation on the direct current side with a fixed alternating current voltage is obtained.

In the Dickenson street sub-station of the Manchester Corporation electricity works, three of these converters were in operation. The alternating-current end was wound for 6500 volts, three-phase, 50 cycle, and with this fixed voltage the direct-current pressure could be varied so as to enable the machines to operate on either the 400-volt or 550-volt direct-current bus-bars, with an output of 1200 amperes, and 900 amperes, respectively.

The engineer in charge of this station stated that exceedingly heavy overloads do not pull these machines out of step. Their synchronizing properties, facility of handling, stability of operation, etc., are very much the same as that of synchronous converters on the same system.

The starting is done from the alternating current side end by means of resistance inserted into the rotor winding which is connected to the slip-rings.

Hall of Fame

The Institute was officially represented by Mr. William J. Hammer on Memorial Day, at the second unveiling of tablets in honor of great Americans at the Hall of Fame, University Heights, New York City. The exercises were very impressive, orations being delivered by Governor Hughes of New York and Governor Guild of Massachusetts. Mr. Hammer in behalf of the American Institute of Electrical Engineers placed a beautiful wreath suitably inscribed upon the tablet of Samuel F. B. Morse, which was unveiled at the first ceremony six years ago when the Institute was similarly represented by Mr. Gano Dunn.

Submarine Signaling

The first pneumatic bell used on a submarine vessel was installed on the Octopus, by H. S. Wilson, prior to her recent trials at Newport, R. I. The results obtained were entirely satisfactory, and orders arranged on a code were transmitted several miles through the water, and signals given to the Octopus for firing her torpedoes, when submerged, etc.

Mr. Wilson was also engaged on other interesting work, placing electric bells on the ocean bed off Boston Light, Mass., and at Chibucton Head, Halifax, Nova Scotia. These bells are operated from a shore station about two and a half miles distant.

Sections and University Branches

BALTIMORE SECTION

Thirty members of the Baltimore Section held a meeting at the Johns Hopkins University on June 21, 1907. John B. Whitehead presided. The following officers were elected to serve during the ensuing year: John B. Whitehead, chairman; Charles G. Edwards, secretary; Charles E. Phelps, Jr., P. O. Keilholtz, H. A. Foster, H. W. Peck, W. D. Young, executive committee, Mr. P. O. Keilholtz read a paper on the "Progress in Low-Frequency, Alternating-Current, Incandescent Lighting."

CHICAGO SECTION

High-tension transmission was the subject for discussion at the special meeting of the American Institute of Electrical Engineers in the Auditorium Hotel, Chicago, on May 24. It was the largest meeting ever held under the auspices of the Chicago Section, about 200 being present when the meeting opened at 9 o'clock in the morning. Besides the value of the discussion, those present enjoyed the hospitality of the local committee in the form of a tasteful dinner in the palm room of the auditorium, and later there was a trip and inspection tour to the large new hydroelectric plant of the Grand Rapids and Muskegon Power Company on the Muskegon River in Michigan.

The whole event from the opening of the meeting on Friday morning to the return of the steamer Puritan on Sunday morning was highly profitable and greatly enjoyed by all. To Messrs. P. B. Woodworth and George A. Damon of the local committee, Mr. P. M. Lincoln of Pittsburg and Mr. F. E. Greenman of the power company is due much credit for the success of the meeting and excursion.

Professor P. B. Woodworth of Lewis Institute, Chicago, chairman of the Chicago Section, called the meeting to order on Friday morning, and after a few remarks in which he called attention to the series of meetings arranged by the High-Tension Transmission Committee, introduced P. M. Lincoln of Pittsburg. Mr. Lincoln took charge of the discussion in place of Ralph D. Mershon of New York, chairman of the committee, who was unable to attend on account of an attack of tonsilitis.

Discussion of high-tension problems was based on five papers, as follows: "Relative Merits of Three-phase and One-phase Transformers," by H. W. Tobey of the General Electric Company; "Relative Advantages of One-phase and Three-phase Transformers," by John S. Peck of the British Westinghouse Electric Company; "Potential Stresses as Affected by Overhead Grounded Conductors," by R. P. Jackson of the Westinghouse Electric Company; "Forced Oil and Forced Water Circulation for Cooling Oil-insulated Transformers," by C. C. Chesney of the Stanley Electric and Manufacturing Company; "Open vs. Enclosed High-voltage Station Wiring," by F. O. Blackwell of New York. The papers and discussions were not presented as covering the whole field of the subjects discussed, but brought out the salient features on which differences of opinion might exist. Messrs. Tobey, Peck, Chesney, and Blackwell were not present and their papers were read respectively by W. S. Moody, J. W. Farley, C. W. Stone, and W. S. Moody. The first two papers being on the same general subject, they were discussed together.

The last meeting of the Chicago Section for the Institute year 1906–7 was held on Tuesday, June 11, 1907, at 8 o'clock, in the rooms of the Western Society of Engineers.

Mr. E. T. Adams, general manager of the gas-engine department of the Allis-Chalmers Company, Milwaukee, read a paper on, "The Application of Large Gas Engines to Electrical Units." Slides were used to illustrate local and foreign practice, and an interesting discussion followed.

CINCINNATI SECTION

The regular annual banquet and meeting of this Section was held at Schuler's Cafe, Wednesday evening, May 29, 1907. The following officers were elected to serve during the ensuing year: Mr. G. A. Wessling, president; Mr. Budd Frankenfield, vice-president; Mr. A. C. Lanier, secretary. The business meeting was followed by the reading and discussion of the following two papers: "Three-phase vs. Single-phase Transformers", and "Station Wiring". Much interest was manifested in the discussion.

UNIVERSITY OF COLORADO BRANCH

This branch held two meetings during May 1907. On May 8, an address was given by Mr. Appolter, on the Northern Colorado Company's new central station at Lafayette, Colorado. At the second meeting a paper was presented by Mr. Eby on the Moore lamp.

The following officers have been elected to serve during the ensuing year: Mr. A. M. Gregg, president; Mr. H. S. Buchanan, secretary-treasurer. The prospects for increased membership and interest in this Branch are very promising. Most of this year's Students have been graduated and are going East to enter the employ of some of the large manufacturing and operating companies.

COLUMBUS SECTION

At a meeting of this Section, held June 3, 1907, the following officers were elected to serve for the ensuing year: Mr. R. J. Feather, chairman; Mr. H. L. Backman, secretary; Messrs. W. A. Wolls and R. E. Manley, managers.

UNIVERSITY OF MONTANA BRANCH

The Associates and Students who applied for permission to organize the University of Montana Branch, met on May 24, 1907 and elected the following officers: Professor Robert Sibley, chairman; George Slack, vice-chairman; C. H. Christensen, treasurer; and S. R. Inch, secretary.

It was also determined that the above named persons should comprise the executive committee. There were thirteen Associates and Students of the Institute present at the meeting and it is believed that upon the resumption of actual work next September the Branch will number twenty to twenty-five members.

It was further decided that the meetings should be held on the first Thursday of every month, the first meeting of the Branch to be held on October 3, 1907. During the evening a very interesting paper was read by Professor Sibley entitled "The Bedell System of Composite Transmission of Electrical Energy", the subject being well illustrated by experiments.

The membership of the Branch is very enthusiastic and there is every indication that the organization will be very helpful to the university, and that the aims and purposes of the American Institute of Electrical Engineers will be promoted in this locality by the work of the Branch.

PHILADELPHIA SECTION

The thirty-eighth meeting of the Philadelphia Section of the American Institute of Electrical Engineers was held on June 17, 1907, in the roof-garden of the Manufacturers' Club of Philadelphia. This being the annual meeting, the first business was the election of officers for the coming year.

The chairman, Mr. W. C. L. Eglin, appointed Messrs. Bernstein and Manypenny tellers, who after counting the ballots reported the election as follows:

Total number of votes cast 52, distributed as follows:

Chairman, J. F. Stevens, 52 votes; secretary-treasurer, H. F. Sanville, 52 votes; assistant secretary, L. J. Costa, 52 votes; managers, E. F. Northrop, 46 votes; Geo. Hoadley, 44 votes; Charles Day, 41 votes; H. C. Snook, 13 votes; C. Bonine, 8 votes; E. P. Coles, 4 votes.

Messrs. Stevens, Sanville, Costa, Northrop, Hoadley, and Day were declared elected to the respective offices as indicated by the ballot.

The entertainment committee had provided a vaudeville-smoker for the balance of the evening and the business part was adjourned. There were 104 visitors and members present.

SEATTLE SECTION

The Seattle Section held its annual convention at Spokane on June 15–16, 1907.

A number of the members and their friends left on the Great Northern Friday evening, June 14, 1907, at 8 o'clock and arrived in Spokane at 9:45 o'clock the next morning.

Saturday, June 15, 1907 was spent in examining the single-phase railway system of the Spokane Inland Electric Railway. A meeting was held that evening in Spokane at 8 o'clock. J. B. Ingersoll read a paper on the "Single-Phase System of Railways." Professor C. Edward Magnusson was instructed as to the needs of the members west of the Rocky Mountains, so that he will be able to represent this membership at the A. I. E. E convention, to which he goes as a delegate.

On the following Sunday several interesting trips were taken in and around Spokane. We returned home Sunday evening, arriving in Seattle early Monday morning.

TOLEDO SECTION

This section was formally organized at a meeting held in the Smith & Baker Building, on June 3, 1907. The following officers were elected to serve during the ensuing year: Mr. W. G. Nagel, president; Mr. George E. Kirk, secretary; Messrs. Richards, Nickels, Kirk, Dorman, and Nagel, executive committee. Mr. W. E. Richards was unanimously chosen as alternate-delegate to the Niagara Falls Convention. Mr. Brown, of Lynn, Mass., gave an instructive and interesting talk on the construction and operation of mercury rectifiers. The Institute paper on the Rowland Telegraphic System was then abstracted by Mr. George E. Kirk. This Section will resume activity early in the autumn.

WASHINGTON SECTION

The annual business meeting of this Section was held on June 8, 1907. Mr. Paul Burton was elected chairman, Mr. Philander Betts was re-elected secretary, Professor F. A. Wolff, Major Edgar Russell and Mr. E. E. Clement were elected the three other members of the executive committee. The Section will suspend activity during the summer months.

Associates Elected

At a regular meeting of the Board of Directors held in the Engineers' Building, 33 West Thirty-ninth street, New York, Friday, June 21, 1907, at 3:30 p. m., the following 271 Associates were elected:

AANES, OTTO RUTHERFORD, Superintendent, Brookings Light, Heat, and Water Department, Brookings, S. D.

ADAMS, JULIAN, Electrical Engineer, Pacific Electric Railway Co.; res., 735 Francisco St., Los Angeles, Cal.

ASHBRIDGE, DONALD MACQUEEN, Electrical Engineer, Malcolm M. Hill Co.; res., Oak Lane, Philadelphia, Pa.

ATKINSON, ALBERT A., Professor of Physics and Electrical Engineering, Ohio University, Athens, Ohio.

ATKINSON, THOMAS WILSON, Professor of Physics and Electrical Engineering, Louisiana State University, Baton Rouge, La.

BACKUS, CYRUS DAY, Assistant Examiner, United States Patent Office; res., 1017 P. St., Washington, D. C.

BAILEY, JOSEPH HARRY, Engineer and Salesman, K. C. C. & B. Mfg. Co., 1110 McGee St.; res., 642 Park Ave., Kansas City, Mo.

BANNING, THOMAS ALLEN, JR., Student, Armour Institute of Technology; res., 5610 Madison Ave., Chicago, Ill.

BARNES, WELDEN FAIRBANKS, Correspondent, Westinghouse Electric and Mfg. Co., Kansas City. Mo.

Barrett, William Alexander, Meter Inspector, Missoula Light and Water Co., Missoula, Mont.

Barrows, William Edward, Jr., Instructor Electrical Engineering, Armour Institute of Technology; res., 908 E. 60th St., Chicago, Ill.

Bartlett, Enoch Joseph, Assistant Engineer, Electric Vehicle Co.; res., 35 Laurel St., Hartford, Conn.

Beals, William Bryant, Block Inspector, Chesapeake and Potomac Telephone Co., Baltimore, Md.

Beazley, Arthur Tetley, Assistant, General Electric Co.; res., 241 Liberty St., Schenectady, N. Y.

Beckstrom, John A., Superintendent, Switchboard Department Tri-State Telephone and Telegraph Co.; res., 1108 Jessie St., St. Paul, Minn.

Beckwith, Edward Pierrepont, Engineer, General Electric Co., Schenectady; res., Garrison, N. Y.

Belfield, Reginald, Manager, Westinghouse Patent Bureau; res., 2 Norfolk St., Strand, London, W. C. Eng.

Belt, William Bradley Tyler, Superintendent, Nebraska Telephone Co., 202 S. 18th St., Omaha, Neb.

Beneze, William, Chief Electrician, Maryland Telephone Co.; res., 124 Stafford St., Baltimore, Md.

Bernhardt, David F., Chief Electrician, J. B. King & Co., 402 Richmond Terrace, New Brighton, S. I., N. Y.

Bidwell, Carlyle D., Sub-Foreman, Western Electric Co.; res., 2633 N. Hermitage Ave., Chicago, Ill.

Bigelow, Horatio, Consolidated Railway Co., Norwich, Conn.

Bingham, Albert Raiguel, Operator, Hudson River Electric Power Co., Albany; res., Spier Falls, N. Y.

Bishop, Warren Joseph, Erecting Engineer, Allis-Chalmers Co.; res., 904 Summit Ave., Milwaukee, Wis.

Bivins, Walter Thomas, Engineer Electrical Equipment, United Railroads; San Francisco, Cal.

Black, Newton Henry, Instructor, Physics and Chemistry, Roxbury Latin School, Boston, Mass.

Blakeney, Henry Geisen, Tester, Dallas Electric Light and Power Co., Dallas, Texas.

Bradford, William, Superintendent, of Manufacture, Lincoln Gas and Electric Light Co., Lincoln, Neb.

Bright, Herbert Loose, Inspector and Draftsman, New York Central and Hudson River Railroad, New York City.

Brofos, Einar, Assistant Chief Engineer, American Electric Telephone Co.; res., 891 N. 40th Court, Chicago.

Brown, Clarence Clapp, Assistant Engineer, Bell Telephone Co., 11th and Filbert Sts., Philadelphia, Pa.

Brown, Percy M., Operator, Huronian Co., High Falls, Ont.

Bullock, Frank E., District Inspector, Chesapeake and Potomac Telephone Co.; Baltimore, Md.

Burns, Harvey Lynn, Telephone Engineer, Western Electric Co., 463 West St.; res., 10 W. 64th St., N. Y. City.

Burt, Austin, General Superintendent, Citizens Gas and Electric Co., Waterloo, Iowa.

Bush, Henry F., Jr., Erecting Engineer, Westinghouse Electric and Mfg. Co.; Philadelphia, Pa.

Cary, Edward Egbert, President and Treasurer, Edward E. Cary Co., 59 Park Place, New York City.

Carter, Charles Edward, Superintendent of Distribution, Madison Gas and Electric Co., Madison, Wis.

Carter, Wilson Andrus, Electrical Engineer, Denver Gas and Electric Co., 405 17th St., Denver, Colo.

Caufield, J. J., Commercial Electrical Engineer, General Electric Co.; res., 40 Glenwood Blvd., Schenectady.

Chamberlain, Frederick Arthur, Electrical Engineer, American Gas and Electric Co., Philadelphia, Pa.

Chapman, Allan, Works Engineer, E. R. Thomas Motor Co., Buffalo, N. Y.

Chappelow, Fay Eldon, Installer, Stromberg Carlson Telephone Mfg. Co., Rochester, N Y.

Christensen Christian H., Missoula Light and Water Co., Missoula, Mont.

CLARKE, HENRY PHILIP, Master Mechanic, New York City Railway Co.; res., 133 W. 140th St., New York City.

CLEWELL, CLARENCE EDWARD, Instructor, Electrical Engineering, Lehigh University, Bethlehem, Pa.

COUSSIRAT, HENRY ALFRED, Assistant Engineer, New York Telephone Co., 15 Dey St.; New York City.

COOPER, DRURY W., Member of Firm, Kerr, Page and Cooper, 149 Broadway, New York City.

CORRIGAN, EDWARD, Superintendent, Chesapeake and Potomac Telephone Co., 5 Light St., Baltimore, Md.

CRANE, EDGAR WILLIS, General Manager, Segura Braniff y Cia, Orizaba, Vera Cruz, Mexico.

CROSBY, GEORGE LOCKE, Sales Engineer, Crosby, Craft and Co., 723 Williamson Bldg., Cleveland, Ohio.

CURRENT, GUY LEROY, Deskman, New York and New Jersey Telephone Co., 547 Clinton Ave., Brooklyn, N. Y.

DANNER, JAKE, Western Electric Co., Chicago, Ill.

DAVIS, NELSON B., Electrical Draftsman, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

DAVISSON, HENRY LAWRENCE, Assistant Engineer of Storage Batteries, New York Edison Co., New York City.

DEREMO, LEONARD J., Consulting Engineer, Fourth National Bank Bldg.; res., College Hill, Cincinnati, O.

DEVED, HORACE WARREN, Assistant to Engineer, Westchester Lighting Co., Mount Vernon, N. Y.

DIEHL, HARRY EVERETT, Telluride Power Co., Provo, Utah.

DINSMORE, JOSEPH PAUL, Telephone Engineer, Western Electric Co., 259 S. Clinton St., Chicago, Ill.

DORMAN, HARRY BOWERS, Chief Draftsman, Toledo Railways and Light Co., Toledo, Ohio.

DORNEY, JAMES JOSEPH, Westinghouse Electric and Mfg. Co., St. Louis, Mo.

DOWNEY, JAMES NETHERMARK, Assistant Superintendent Camden Coke Co., Camden, N. J.

DOWNING, RICHARD COLLINS, Inspection and Testing, Niagara Lockport and Ontario Power Co., Buffalo, N. Y.

DREHER, HERBERT CLARENCE, Local Manager, Edison Electric Illuminating Co., Tamaqua, Pa.

DUCKETT, ALONZO L., Arc Light Superintendent, Asheville Electric Co., Asheville, N. C.

EELLS, HENRY WILSON, Assistant, Electrical Engineering Department, J. G. White and Co., New York City.

ELLIS, ALFRED GEORGE, Chief Assistant and Manager, H. M. Hobart, Norfolk St., Strand, London, Eng.

ELLIS, EBENEZER DUNN, Superintendent and Manager, Plant City Ice and Power Co., Plant City, Fla.

EVANS, ROBERT PENNAL, JR., Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

FAIRBANKS, CHARLES EDWIN, Chief of Central Office Equipment, New York and New Jersey Telephone Co., 15 Clinton St., Newark, N. J.

FLINT, LOUIS JOSEPH, Kellogg Switchboard and Supply Co., Chicago, Ill.

FOSTER, FRANK HERBERT, Electrical Department, Long Island Railroad Co., New York City.

FOX, THOMAS EDWARD, Superintendent Electric Lighting Plant, Consolidated Railway Co., Greenwich, Conn.

FOX, WALTER GORDON, Assistant Chief Engineer, Ferrocarril al Curaray, Ambato, Ecuador, S. A.

FRANTZ, HOWARD M., Manager Electrical Department, H. W. Johns Manville Co., 173 Randolph St., Chicago.

FULLER, JOHN T., Chief Engineer, Phosph. Mining Co., Plant City, Fla.

FUNK, NEVIN ELWELL, Instructor Electrical Engineering, Georgia School of Technology; Atlanta, Ga.

GABAY, HARRY RUTHERFORD, Underground Engineer, New York Telephone Co., 15 Dey St., New York.

GABOURY, JOHN DOLAN, General Manager, Alabama City, Gadsen and Attala Railway Co., Gadsen, Ala.

GAY, FRAZER WALKER, Electrical Engineer, Crocker-Wheeler Co., Ampere.

Gerhardt, Philipp Wilhelm, Testing Department, General Electric Co.; res., 905 State St., Schenectady, N. Y.

Gibson, Charles Bradley, Designing Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

Gilbert, Joseph N., Chief Engineer, National Construction and Equipment Co., Norwich, Conn.

Gill, Clyde Ross, Superintendent Electrical Distribution, Sacramento, Cal.

Goldberg, Harry, Bond Tester, Long Island Railroad Co., New York City.

Gottlieb, Edward, First Lieutenant, U. S. Army, Boston, Mass.

Gould, Mortimer Dickinson, Inspecting Engineer, Niagara, Lockport and Ontario Power Co., Buffalo, N. Y.

Graham, Alfred James, Wire Chief, New York and New Jersey Telephone Co., Brooklyn, N. Y.

Grant, William Wright, Manager, American Conduit Co., 140 Nassau St., New York City.

Green, Francis Vinton, Vice-President, Ontario Power Co., Buffalo.

Gulick, Ray Alexander, Mount Whitney Power Co., Visalia, Cal.

Haar, Selby, Engineer, General Electric Co., Schenectady, N. Y.

Haldy, Frederick George, Yale and Towne Mfg. Co., Stamford, Conn.

Hamilton, Lansdale Ellis, Dean Electric Co., Elyria, Ohio.

Hansen, John Penfield, Wire Chief, Chicago Telephone Co., Joliet, Ill.

Harrington, Alfred Lewis, Erecting Engineer, General Electric Co., 1518 Park Building, Pittsburg, Pa.

Harrington, John Leroy, Telephone Engineer, Western Electric Co., N. Y.

Harris, Edson Sheppard, Salesman, Dolier Engineering Co., 119 South 11th St., Philadelphia, Pa.

Harrison, O. L., Construction Engineer Electric Storage Battery Co., 1400 Association Building, Chicago, Ill.

Hart, Harry U., Chief Engineer, Can. Westinghouse Co., Hamilton, Ont.

Hartzell Walter L., Erection Engineer, Westinghouse Electric and Mfg. Co., Baltimore, Md.

Helmholtz, Arthur William, Assistant Engineer, and Draftsman, with G. H. Rowe, Chicago, Ill.

Henderson, Matthew Cochrane, Assistant Electrical Engineer, Dunedin City Corporation, Dunedin, N. Z.

Henderson, Roy Manwaring, Engineer, Arnold Co., 181 LaSalle St.; res., 285 East 65th Place, Chicago, Ill.

Hess, Wilhelm, Compagine d'Electricite Alirth, Bale, Munchenstein, Switzerland.

Hessin, James H., General Manager, Bloomington, Pontiac and Joliet Electric Railway, Pontiac, Ill.

Hill, Arthur St. John, Student, Polytechnic Institute, Brooklyn, N.Y.

Hill, Thomas A., Consulting Engineer, and Attorney 170 Broadway, New York City.

Hill, William Ameal, Electrician, Pope Motor Car Co., Toledo, O.

Hinrichsen, Edward E., Western Electric Co., Chicago, Ill.

Hixon, Alfred, J., with E. C. Lewis, 121 Federal St., Boston, Mass

Hoff, Christopher, Jr., Electrical Engineer, Lee and Hoff Manufacturing Co. St. Paul, Minn.

Hoff, Earl Bourie, Electrician, Pope Motor Car Co., Toledo, O.

Hope, Harry LeRoy, Telephone Salesman Western Electric Co., 259 South Clinton St., Chicago, Ill.

Hoppenstedt, Edward Henry, Clerk, B. H. Howell Son and Co., 109 Wall St., New York City.

Houck, Henry Craft, Manager Supply Department, General Electric Co., Cincinnati, Ohio.

Houghtaling, Walter A., Engineer, Rowland Telegraphic Co., Baltimore.

Howard, James Franklin, Experimentalist, Jersey Shore, Pa.

Howk, Clarence Leroy, Telephone Engineer, Western Electric Co.; res. 1143 W. Fullerton Ave., Chicago, Ill.

Hoy, Howard Hartman, Instructor in Electrical Engineering, South Dakota State College, Brookings, S. D.

HULBERT, JOHN W., JR., Chief Electrician, Auburn State Prison; res. 42 Seminary St., Auburn, N. Y.

HUNT, H. H., District Manager, Stone and Webster, Savannah, Ga.

HUNT, JOHN HERMAN, Instructor in Electrical Engineering, Washington, University, St. Louis, Mo.

ITOH, JUNZO, Electrical Engineer, Municipal Electric Railway Department, City Hall; Osaka, Japan.

JAMES, HENRY PHILIP, Bryant Electric Co., Bridgeport, Conn.

JONES, ARTHUR LUCAS, Electrical Engineer, General Electric Co., res. 841 Union St., Schenectady, N. Y.

JONES, JOSEPH HENRY, Utah Light and Railway Co., Salt Lake City, Utah.

JONES, SAMUEL BERIAH, Construction Foreman, General Electric Co., Schenectady, N. Y.

JONES, STERNS FRANCIS, Assistant Electrical Engineer, Postal Telegraph Cable Co., 253 Broadway, New York City.

JONES, WILLIAM SIGLER, Selling Agent, Motor Car Specialty Co., 112 North Broad St., Philadelphia.

JOSEPHI, ROBERT, Chemical Importing and Manufacturing Co., 72 Pine St.; res., 28 W. 95th St., New York City.

KELLOGG, RICHARD BELA, Draughtsman Hartford Electric Light Co., Hartford.

KERR, DAVID J., Electrician, Champion Fiber Co., Canton, N. C.

KNAUR, RICHARD I., Director, Felten and Guilleaume, Vienna, Austria.

KOS, DIRK, Ontario Power Co., Niagara Falls, N. Y.

KOSCHCRAK, FERDINAND, Engineer, Thomson Houston Co., 219 Rue de Vangirard, Paris, France.

KYSER, HENRY HEARST, Engineer, Talladega Planing Mill and Lumber Co., Talladega, Ala.

LANE, EMMETT HORACE, Assistant, Department of Water Supply, Brooklyn, N. Y.

LANGDELL, JOSEPH CHESTER, Meter Expert, Hudson River Power Co.; res., 28 Chestnut St., Albany, N. Y.

LEIGHTON, CLIFFORD HENRY, Chief Electrician, Saco and Pettee Machine Co., Boston, Mass.

LENNARD, WILLIAM HENRY, Electrical Engineer, Houghton Elevator and Machine Co., Toledo, O.

LEWIS, ISAAC NEWTON, Instructor, Department Electricity, Fort Monroe, Va.

LITTLE, CLARENCE DUANE, Tester, Westinghouse Electric and Mfg. Co., Newark, N. J.

LOOMIS, EVERETT ERASTUS, Tester, General Electric Co., Schenectady, N. Y

LEHOSE, FRANCIS MAC, Regulator, New York Edison Co., 151 E. 39th St., New York City.

MACNUTT, BARRY, Assistant Professor, Physics, Lehigh University, South Bethlehem, Pa.

MCCLINTOCK, WILLIAM MCKEAN, Electrical Engineer, McClintock Manufacturing Co., St. Paul, Minn.

MCCLURE, O. D., Master Mechanic, Cleveland Cliffs Iron Co., Ishpeming.

MCDONALD, CHARLES BRENNECKE, Electrical Engineer, Florida East Coast Hotel Co., Palm Beach, Fla.

MCDOUGAL, JOHN HAYNES, Assistant Professor of Electrical Engineering, Ore. Agri. College, Corvallis, Ore.

MCFEDRIES, SHERMAN MILLER, Secretary and Treasurer, J. L. Schureman Co., 80 W. Jackson Blvd., Chicago.

MAHONEY, JOSEPH MICHAEL, Inspector, City of Boston Wire Department; res., 21 Bailey St., Boston, Mass.

MALTMAN, JOHN SCOTT, Superintendent, Electric Light Co., Kankakee, Ill.

MARKEL, HARLEY R., Electrical Inspector, Ohio Inspection Bureau, 520 Dollar Bank Bldg., Youngstown, Ohio.

MATHER, ROBERT FENTON, Assistant Superintendent, Winnipeg Electric Street Railway Co., Lac du Bonnet, Manitoba.

MATTHEWS, HUBERT WILLARD, Engineering Apprentice, Westinghouse Electric & Mfg. Co., Great Falls, S. C.

MEADOWS, GEORGE WILLIAM, Wireman, Jamestown Exposition Co.; Pine Beach; res., Lambeth Point, Va.

MERIWETHER, RICHARD, Superintendent, Louisville and Eastern Railroad, 511 West Green St., Louisville, Ky.

MILLER, WILLIAM NORTON, Assistant Electrical Engineer, Detroit River Tunnel Co., Detroit, Mich.

MILTON, TALIAFERRO, Engineer, Electric Storage Battery Co., Citizens Bank Building, Cleveland, O.

MINEHARDT, ERNEST HENERY, Operator, New Milford, Power Co., Gaylordsville, Conn.

MOORE, HENRY DUBOIS BAILEY, Engineer, Western Electric Co., N. Y. City.

MORGENSTERN, OTTO LESTER, Student, Brooklyn Polytechnic Institute; res. 77 Sumner Ave., Brooklyn, N. Y.

MORRELL HARRY B., Foreman Meter Department, New York, Queens Light and Power Co., Brooklyn, N. Y.

MORSHEAD, LESLIE ROBERT, Technical Representative, British Insulated and Hesby Cables Ltd., Prescot, Eng.

MUNROE, WILL S., Superintendent of Wiring, Stone and Webster, 6th and Ohio Sts., Terre Haute, Ind.

MURTY, HARRY ELIAS, Superintendent Shamokin Light Heat and Power Co., Shamokin, Pa.

NEIMAN, WILLIAM FRANKLIN, Power Solicitor, San Francisco Gas and Electric Co., Berkeley, Cal.

NEWBOLD, ROGER MERRICK, Electrical Engineer, Adams and Westlake Co., 110 Ontario St., Chicago, Ill.

NEWCOMB, ROBERT EVERETT, res. 57 Fairfield Ave., Holyoke, Mass.

NIXON, GEORGE, Copartner, Nixon and Kimmel, Spokane, Wash.

NORMAN JOHN ARTHUR, Terre Haute, Indianapolis and Eastern Traction Co., Terre Haute, Ind.

NORRIS, MARVIN L., Draftsman, Fort Wayne, Electric Works, 115 West Taber St., Fort Wayne, Ind.

NOWLAN, EDWARD ALONZO ROSSEAU, Telephone Engineer, Western Electric Co., Chicago, Ill.

OAKMAN, HENRY B., Sales Engineer, Bullock Electric Co., 39 Cortlandt St., New York City; res. Linden, N. J.

O'FARRELL, RICHARD WILLIAM, Clerk, Cordoba Electric Light and Power Co., Cordoba, Argentine Republic.

OSGOOD, HARRY WHITNEY, Assistant Electrical Engineer, Stone and Webster, 84 State St., Boston, Mass.

PARSONS, PHILIP DOUGLAS, Telephone Engineer, Western Electric Co., 463 West St., New York City.

PEASE, LEWIS ADAMS, Designing Engineer, Chicago and Milwaukee Electric Railroad Co.; res. Highwood, Ill.

PERRY, LUTHER PACKARD, Superintendent, Fries Mfg. and Power Co., Winston-Salem; res. Clemmons, N. C.

PINCKNEY, THEOPHILUS, Chief Engineer Asheville Electric Co.; res. 169½ Patton Ave., Asheville, N. C.

PLUMLEY, HAROLD, Assistant to District Sales Manager, Fort Wayne Electric Works, Chicago, Ill.

POPE, ARTHUR EDWARD, Assistant, Engineering Department, J. G. White and Co., New York City.

POTTER, ARVIN HENRY, Chief Installer, Tri-State Telephone and Telegraph Co., Minneapolis, Minn.

PRESS, ABRAHAM, Electrical Engineer, Bureau of Yards and Docks Navy Department, Washington, D. C.

PRUESSMAN, OTTO, Telephone Engineer, Western Electric Co., res. 1484 Roscoe St., Chicago, Ill.

PURSE, WALTER BRANCH, Superintendent Distribution, Savannah Electric Co., Savannah, Ga.

RAMSEY, ALLAN, Union Electric Light and Power Co., 10th and St. Charles St., St. Louis, Mo.

RANKIN, ROBERT, Electrical Engineer, Sao Paulo Tramway Light and Power Co., Sao Paulo, Brazil.

RANNEY, EARL EUGENE, Electrician By-products Coke Co., S. Chicago, Ill.

RANNEY, AMBROSE ELLIOTT, Engineer, Elmore Automobile Co., 1851 Broadway, New York City.

RAPELJE, CHARLES VANDERVEER, Superintendent, Traction Equipment Co., 72 Grand Ave., Brooklyn, N. Y.

RAPELJE, P. DITMARS, Engineer of Services, New York Edison Co., New York City.

Redshaw, William Arthur, Electrical Engineer, Public Service Corporation of N. J.; res. New Brunswick, N. J.

Reynders, Arthur Bernard, General Engineer Insulation Work, Westinghouse Elec. and Mfg. Co., Pittsburg.

Richardson, Charles Dana, Assistant in Electrical Engineering, Mass. Institute of Technology, Boston, Mass.

Rickenbacher, Albert Dominick, Electrician, J. G. White and Co.; res. 1213 G. St. N. W., Washington, D. C.

Roberts, Oswald Mortimer, Superintendent, Orangeburg Electric Light and Water Plant, Orangeburg, S. C.

Roberts, William, Superintendent Motive Power, Northern Ohio Traction and Light Co., Akron, Ohio.

Robinson, Jay Alexander, General Electric Co., Pittsfield, Mass.

Robinson, Percy Gilmour, Tri-State Telephone and Telegraph Co., St. Paul, Minn.

Rooney, John Joseph, Vice President and General Manager, Rooney Electric Lamp Co., 155 East 23rd St., New York City; res. Scarsdale, N. Y.

Roth, Rodolfo, Engineer, traveler, Victor M. Broschi; res. Cadena St. No. 2, Mexico City, Mex.

Russell, Leonard Pomeroy, Student, Massachusetts Institute of Technology, Boston, Mass.

Sadler, DeHope, Operator, Southern Power Co., Great Falls, S. C.

Sager, Lawrence Kingsley, Patent Lawyer and Electrical Expert, 220 Broadway, New York City.

Sakai, Yasudiro, Engineering Department, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

Sawyer, William McCrillis, Electrical Engineer, Bodwell Water Power Co., Bangor, Maine.

Sayer, Eugene Young, Vice President, and General Manager, Improved Equipment Co., New York City.

Schaefer, Edward Franklin, Poto Mines Corporation Rinconada Mining Co., New York City.

Schroeder, Frederick Albert, Superintendent Roll Department, Cambria Steel Co., Johnstown, Pa.

Schuermann, Julius, Manager, Star Electric Fuse Works, Wilkes-Barre.

Seaver, Walter Hibbard, Assistant Sales Agent, American Steel and Wire Co., San Francisco, Cal.

Seixas, Theodore Griswold, Manager, American Instrument Co., Singer Building, New York City.

Shepherd, George Elwood, Shepherd and Rust, Wilkes-Barre, Pa.

Shover, Barton Roy, Electrical Engineer, Indiana Steel Co., Gary Ind.

Sibbald, John, Mechanical Engineer, Fonda, Johnstown and Gloversville Railroad Co., Gloversville, N. Y.

Silver, Arthur Elmer, Chief Electrician, Raleigh Electric Co., Raleigh, N. C.

Silverman, Mortimer, Electrical Engineer, Western New York and Pennsylvania Traction Co., Olean, N. Y.

Simpson, Frank N., Superintendent Electric Power, General Electric Co., Minneapolis, Minn.

Skiff, Warner M., In charge Technical Publicity, National Electric Lamp Association, Cleveland, Ohio.

Sloan, Matthew Scott, Birmingham Railway Light and Power Co., Birmingham, Ala.

Smeaton, James Hugh, Superintendent Generating Station, Winnipeg, Electric Railway Co., Lac du Bonnet.

Smith, Ernest Frank, Superintendent, of Sub-stations, Chicago Edison Co., 139 Adams St., Chicago, Ill.

Smith, George Wallace, Tutor, Electrical Engineering University of Texas res. 1908 Whitis Ave., Austin, Texas.

Smith, Henry Gilbert, Demonstrator, School of Practical Science; res. 322 Logan Ave., Toronto, Ont.

Smith, James Macdonald, Electrical Engineer, Crocker-Wheeler Co., Ampere, N. J.

Soans, Cyril Arthur, Electrical Engineer, Bell Selector Telephone Co., 1703 Melrose St., Chicago, Ill.

Stack, John, Chief Operator, Northwestern Elevated Railroad Co.; res. 616 West 19th St., Chicago, Ill.

STEEN, HARRY ANDREW, Designer of Electrical Apparatus, Westinghouse Electric and Mfg. Co., Pittsburgh.

STEINER, HENRY LOUIS, Battery Engineer, Cleveland Electric Railway Co., Cleveland, Ohio.

STEVENS, HENRY RAYNOR, Electrical Engineer, Archibald S. Downey, 624 Bailey Building, Seattle, Wash.

STILLMAN, HARRY NOYES, Instructor Electrical Engineering Spring Garden Institute, Philadelphia, Pa.

STOWE, FRANK RABINEAU, Operator, Power Transit and Light Co., Bakersfield, Cal.

STURGESS, FREDERICK MEYNELL, Student Armour Institute, Chicago, Ill.

SWEENY, JOHN EDWARD, Chief Clerk, Department of Electricity, Jamestown Exposition Co., Pine Beach, Va.

TAYLOR, CHARLES HENRY, Assistant Engineer, Marconi Wireless Telegraph Co., South Wellfleet, Mass.

THORNTON, GEORGE CROSMAN, Electrical Engineer, Thornton Co., Birmingham, Ala.

THROCKMORTON, C. GROSS, Assistant Construction Engineer, Nebraska Telephone Co., Omaha, Neb.

TINGLEY, JOHN BARNES, Salesman, General Electric Co., Madison, Wis.

TOLMAN, W. H. , Director American Museum of Safety Devices; res., 287 Fourth Ave., New York City.

TRISTAN, RAFAEL MANUEL, Student, Pratt Institute; res., 217 Greene Ave., Brooklyn, N. Y.

TUCKER, FRANK STEVENSON, Engineer and Salesman, Westinghouse Electric and Mfg. Co., Charlotte, N. C.

VANRIPER, WILLIAM R., Foreman of Sub-station, N. Y. C. and H. R. R. R. 198th St. and Webster Ave., Bronx, N. Y.

VAWTER, CHARLES ERASTUS, JR., Professor of Physics, Virginia Polytechnic Institute, Blacksburg, Va.

WALDRON, LOUIS D., Salesman, Allis-Chalmers Co., Buffalo, N. Y.

WALKER, LESTER WARREN, North Platte Electric Light and Power Co., North Platte, Neb.

WALL, WILLIAM GUY, Chief Engineer, National Motor and Vehicle Co., Indianapolis, Ind.

WARDER, JOHN HAINES, Secretary, Western Society of Engineers, 1767 Monadnock Building, Chicago, Ill.

WATROUS, CLEVELAND ELMER, Manager New York Office, Cutler Hammer Mfg. Co., 136 Liberty St., New York.

WATTS, CLARENCE EVERETT, Electrical Engineer, Berwind-White Coal Mining Co., Windber, Pa.

WEBSTER, JOHN ENOCH, General Manager, Westinghouse Electric and Mfg Co.; res., 7927 Tacoma St., Pittsburg.

WEED, JAMES MURRAY, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

WESSELHOEFT, ROBERT, Electrical Engineer, Fearon, Daniel and Co., Shanghai, China.

WESTBURY, PAUL AUGUSTUS, Secretary and Electrical Engineer, F. B. Badt and Co., Chicago Ill.

WIEGAND, HENRY J., Superintendent, Cutler Hammer Mfg. Co.; res., 660 17th St., Milwaukee, Wis.

WILLIS, GEORGE MARPOLE, Consulting Electrical Engineer, 1504 Monadnock Block; res., 52 Walton Place, Chicago.

WINTERS, EDWARD E., Contracting and Consulting Engineer, 18 Broadway New York City.

WITHINGTON, BERNARD, Draftsman, Lancashire Dynamos and Motor Co. Ltd.; Manchester, England.

WOOD, GEORGE THOMAS, Foreman, British Thomson Houston Co.; res., 36 Bath St., Rugby, England.

WOODARD, D. CARL, Switchboard Operator General Electric Co.; res., 13 Eagle St. Schenectady, N. Y.

WOODBURY, STEPHEN EDWARD, Engineer, Simplex Electric Heating Co., Cambridge, Mass.

WOODHEAD, LAWRENCE FURNISS, Electrician, American Lumber Co., Alberquerque, N. M.

WOODWELL, JULIAN ERNEST, Inspector of Electric Lighting Plants, U. S. Treasury Department, Washington.

WOOLFENDEN, JOHN JOSEPH, Draftsman, Brush and Allen, 1331 Penobscot Building, Detroit, Mich.

Yates, George Livingston, Traffic Chief, New York Telephone Co., Mt. Vernon, N. Y.

Yeager, William Franklin, Dodge and Day, Drexel Building, Philadelphia, Chester, Pa.

Yochum, Louis George, Foreman, Western Electric Co., New York City.

Zengerle, Joseph Charles, Student, Polytechnic Institute of Brooklyn; res., 164 Suydam St., Brooklyn, N. Y.

Zimmerman, Harry Benjamin, Sales Engineer, Niagara and Lockport Ontario Power Co., Buffalo, N. Y.

Zimmerman, Joseph, Electrical Mechanist, Westinghouse Electric and Mfg. Co., Newark, N. J.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting.

Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before July 26, 1907.

6509 O. C. Rauschenberg, Atlanta, Ga.
6510 W. C. Thayer, East Aurora, N. Y.
6511 F. D. Hall, Somerville, Mass.
6512 C. G. Sakuma, Tokyo, Japan.
6513 J. LeC. Davis, Pittsburgh, Pa.
6514 J. D. Noyes, Philadelphia, Pa.
6515 F. T. Kitt, Sacramento, Cal.
6516 E. M. Rhett, Savannah, Ga.
6517 L. T. Rainey, Cincinnati, O.
6518 A. M. Adolph, Mexico, D. F., Mex.
6519 W. F. Graham, Merriam, Kansas.
6520 A. L. Millard, Chicago, Ill.
6521 J. D. Shaw, Pittsburgh, Pa.
6522 H. M. Van Demark, Bklyn, N. Y.
6523 J. J. Wesley, Brooklyn, N.Y.
6524 W. E. Wickenden, Madison, Wis.
6525 L. C. Crabbs, Toledo, O.
6526 Burch Foraker, N. Y. City.
6527 F. H. Frochlich, Toledo, Ohio.
6528 A. S. Loizeaux, Schenectady, N. Y
6529 M. C. Lloyd, Toledo, O.
6530 K. E. Sommer, Baltimore, Md.
6531 P. S. Biegler, Iowa City, Ia.
6532 R. E. Maynihan, Manchester, Eng.
6533 I. C. Pettie, Ithaca, N. Y.
6534 R. R. Grant, Norfolk, Va.
6535 H. R. Summerhayes, Schenectady.
6536 L. F. Leurey, New Orleans, La.
6537 G. H. Calkins, Buffalo, N. Y.
6538 W. L. Emery, Salt Lake City, Utah.
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6550 J. P. Satterlee, Gales Ferry, Conn.
6551 Arthur Elken, Mexico, D. F., Mex.
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6553 G. E. A. Fairley, St. George, Md.
6554 F. H. C. Whiteway, St. Johns, N. F.
6555 W. H. Floyd, Provo, Utah.
6556 A. S. Peters, Salt Lake City, Utah.
6557 W. R. McGeachim, Manila, P. I.
6558 A. Westman, Schenectady, N. Y.
6559 A. C. Harrington, Albion, N. Y.
6560 H. F. Way, Dunedin, N. Z.

Total, 52.

Engineers' Building

The board of trustees of the United Engineering Society has placed the management of the building in the hands of a house committee, composed of Joseph Struthers, assistant secretary, American Institute of Mining Engineers, chairman; Ralph W. Pope, secretary, American Institute of Electrical Engineers, and Calvin W. Rice, secretary, American Society of Mechanical Engineers. This committee meets weekly, and through superintendent Lambden all matters of importance concerning the administration of the building are brought to its attention for decision. During the active season all members of this committee are on the premises, and the advantages of this direct representation of the owners are already apparent.

Personal

Mr. Roger Mason, electrical engineer is now with the Bond Electric Company, of San Francisco, Cal.

Mr. C. E. Chatfield, of Cornell University, will be with the Robertson Electric Company of Buffalo, N. Y., during the summer months.

Mr. A. S. Fairbanks, is now with the firm of Hering and Fuller, consulting engineers, 170 Broadway, New York City, in charge of construction of sewage disposal plants.

Mr. Howard F. Smith, formerly mechanical engineer for the Louisiana Purchase Exposition, has entered the consulting engineering field, with offices at 1105 Times Building, St. Louis, Mo.

Mr. F. Gangl has left the switchboard department of the General Electric Company at Schenectady, to accept a position in the Birmingham office of Ford, Bacon, and Davis, Birmingham, Alabama.

Mr. H. S. Wilson, recently with the Submarine Signal Company of Boston, Mass., has taken up his old line of work as commercial engineer for the New England Engineering Company of Waterbury, Conn.

Mr. E. H. Seaman, formerly with the Fries Manufacturing and Power Company of Winston-Salem, N. C., is now electrical engineer for Blackall and Baldwin Company, of 41 Cortlandt street, New York City.

Mr. F. C. Weber, formerly superintendent of construction for the Western Electric Company at Omaha, Nebraska, has accepted a position in the engineering department of the Chicago Telephone Company.

Mr. H. W. Protzeller is at present engaged in single-phase railway installation for the General Electric Company, on the lines of the Milwaukee Electric Railway and Light Company, at Milwaukee, Wisconsin.

Mr. J. O. Taylor, formerly with the mechanical division of the Isthmian Canal Commission, has been promoted to assistant engineer in the Colon construction division, with headquarters at Gatem, Canal Zone.

Mr. G. Roscoe Milford has been transferred from Redding, Cal., as chief of construction, to Fern, Cal., as superintendent of power houses, lines, and sub-stations for the Northern California Power Company.

Mr. J. Allan Smith, for the past eight years manager of the Boston office of the Fort Wayne Electric Company, has taken a position with the General Electric Company, to divide his time between New York and Schenectady.

Mr. George H. Usher, formerly superintendent of the Postal Telegraph-Cable Company of New York, has been appointed general superintendent of the southern division of that company with headquarters at Atlanta, Ga.

Mr. E. W. Dean, formerly at South Ealing, London, has received an appointment with the Buenos Ayres and Rosario Railway Company of the Argentine Republic, S. A., and will go to that country in a few months.

Mr. Ludwig Hommel, of Ludwig Hommel and Company, has removed his offices to the Renshaw building, Pittsburg, Pa. Mr. Hommel represents in the Pittsburg territory a number of prominent manufacturers of electrical apparatus.

Mr. Rex T. Stafford has resigned his position as assistant electrical construction engineer at the West Seneca plant of the Lackawanna Steel Company, to become district engineer at the Buffalo sales office of the Allis-Chalmers Company.

Mr. F. M. Walker has left the position of engineer in the contracting department of the Allis-Chalmers Company, to accept that of manager of R. E. Briggs and Company, Incorporated, consulting and contracting engineers, Mexico, D. F.

Mr. Orman B. Humphrey, Associate A. I. E. E., and also Member A. S. M. E has removed his offices to the Sterns Building, 202 Exchange Street, Bangor, Maine, where, as consulting engineer, he will devote his time to hydrcelectric developments and general engineering.

Mr. W. H. Acker, formerly connected with the Connellsville Pa. office of West Penn. Railways Company, is now located at Chorlerai, Pa., being in charge of the same company's sub-stations and high-tension transmission lines, in the Monongahela River district.

Mr. Wilfrid J. B. Drew, who, since June, 1906, has been in charge of the data section of the engineering department of the Canadian General Electric Company at Toronto, has become assistant secretary and treasurer of the Canadian Society of Civil Engineers at Montreal.

Mr. Arthur B. Bond has been transferred from the sales department of the Niagara, Lockport, and Ontario Power Company, to the power department of the Syracuse Lighting Company, which has just been taken over by the United Gas Improvement Company of Philadelphia.

Mr. E. D. Edmonston, chief engineer of the American Construction Company, has recently completed the large commercial power and lighting system of the new Consumers Electric Company of New Orleans, La., and last month took charge of the industrial department of W. S. Barstow and Company.

Mr. C. W. Koiner, who has been occupying the dual position of secretary-treasurer and engineer of the National Light and Improvement Company of St. Louis, has accepted the position of general superintendent and engineer of the Los Angeles Gas and Electric Company, Los Angeles, Cal.

Mr. E. G. Elliott, with the Selby Smelting and Lead Company at So. San Francisco, California, has been transferred to that company's plant at Selby, California, to take charge, as constructing engineer, of the erection of a shot tower, to replace the one destroyed by the earthquake in San Francisco, April, 1906.

Mr. A. S. Kalenborn has resigned his position of assistant electrical engineer for the California Gas and Electric Corporation, to join his former chief in that corporation, Mr. F. G. Baum, in his new field of work. Mr. Kalenborn is in charge of the Seattle office of the company, which has already a good deal of work on hand in that section.

Mr. A. E. Poirier has resigned the superintendency of the repair shop of the New Jersey division of the New York and New Jersey Telephone Company at Newark, and expects to engage in an entirely different line of business next fall. Mr. Poirier was with the Western Electric Company in New York from 1889 to 1896, when he entered the telephone service.

Mr. Karl B. Kumpe, locating engineer, Chicago, Milwaukee, and St. Paul Railway, is now on the Olympic peninsula, with headquarters at Hoquiam, Washington. The Northern Pacific, Union Pacific, and Chicago, Milwaukee, and St. Paul railways, are engaged in a triangular race to reach first the timber section north of Gray's Harbor. This is said to be the largest body of standing timber in the world.

Mr. A. S. Hatch, municipal electrical engineer, has removed from Detroit, Mich., to Cincinnati, O., his present address being 6012 Clason Ave., Madisonville, O. During the past winter, besides his municipal work, he has equipped several large factories in Toledo, O., with electric power service, in which both synchronous converters with direct-current motors, and induction motors were used as required for the proper regulation of the distribution.

Mr. J. R. Spurries has resigned his position in the engineering department of the Westinghouse Electric and Manufacturing Company, to become superintendent of the Fibre Conduit Company Orangeburg, N. Y. Mr. Spurries has spent nine years with the Westinghouse interests, one half of this time with the British Westinghouse company as chief draftsman and assistant superintendent. He returned from Manchester last November, and entered upon his new duties June 21.

Mr. T. E. Daniels, of Logan, Utah, who installed, and for the past four years has operated the Logan City Municipal electric plant as its superintendent and electrical engineer, has resigned, to take a similar position with the High Creek Electric Light and Power Company, with headquarters at Richmond, Utah, for which company he acted as consulting electrical engineer during the construction of the plant which furnishes light and power for Preston, and Franklin, Idaho, and for Lewiston, Trenton, Richmond, and Smithfield, Utah.

Mr. W. J. Richards, who, for the last eighteen months has been in the electrical engineering department of the Allis-Chalmers Company, at Cincinnati, associated with Mr. B. A. Behrend, is now chief engineer for the National Brake and Electrical Company. Previously, while assistant engineer for the National Electric Company, and the Christensen Engineering Company, predecessors of the National Brake and Electric Company, Mr. Richards designed their main lines of direct-current apparatus, including motor-compressors and automatic governors for air-brake purposes.

Books Received.

The following volumes have been received from the McGraw Publishing Company and placed in the Library of the Institute:

Berlin-Zossen Electric Railway Tests of 1903. The first complete translation of the Official Report of the test runs made in Germany late in 1903; with an introduction discussing the general subject of Train Resistance by Louis Bell, Ph.B. 74 pages of text, with 18 illustrations and 38 full-page diagrams, curves and plates. Quarto. New York, McGraw Publishing Company. Price, $3 net.

Introduction. Preparatory Work: Construction of the New Road. Changes in the Overhead Lines. Electrical Equipment of the Cars. Reconstruction of the High-Speed Cars. Measuring Instruments. Signal Apparatus. Results of the Test Runs: Braking and Starting Period. Air and Train Resistance. Power Consumption. Behavior of the Car During Service. Behavior of the New Roadbed During the Tests. Final Remarks. Appendix. High-Speed Electric Railway, Berlin, Hamburg.

Alternating Electric Currents. By Edwin J. Houston and A. E. Kennelly. Fourth edition. 359 pages, 115 illustrations. New York, McGraw Publishing Co. Price, $1 net.

Chapter I.—Introductory. II.—Alternating Electromotive Force and Current. III.—Unipolar Alternators. IV.—Power. V.—Transformers. VI.—Electric Lamps. VII.—Electric Motors. VIII.—Polyphase Currents. IX.—Polyphase Motors. X.—Recent Progress in Alternators. XI.—Some Recent Developments in Transformers.

XII.—Phase Transformation. XIII.—Alternating Current Transmission Lines. XIV.—Synchronous Multiphase Motors. XV.—Converters. XVI.—Induction Motors. XVII.—Turbine Alternators. XVIII.—Alternating Current Traction Motors. XIX.—Alternating Current Switches and Switchboard Services. XX.—Constant Current Transformers.

THE ELECTRIC MOTOR. By Edwin J. Houston and A. E. Kennelly. 377 pages, 122 illustrations. New York, McGraw Publishing Co. Price, $1 net.

Chapter I.—Introductory. II.—Sources of Energy. III.—Elementary Electrical Principles. IV.—Early History of the Electromagnetic Motor. V.—Elementary Theory of the Motor. VI.—Structure and Classification of Motors. VII.—Installation and Operation of Motors. VIII.—Electric Transmission of Power. IX.—Alternating-Current Motors. X.—Rotating Magnetic Fields. XI.—Alternating-Current Transmission. XII.—Miscellaneous Applications of Electric Motors.

STRAY CURRENTS FROM ELECTRIC RAILWAYS. By Dr. Carl Michalke. Translated and edited by Otis Allen Kenyon. Cloth, 100 pages. 34 illustrations. New York, McGraw Publishing Co. Price, $1.50 net.

This book covers the field of leakage currents very thoroughly and appeals to railway engineers, waterworks men, telephone and telegraph engineers and all interested in knowing to what extent these currents are liable to create disturbance and damage, and how such evils can be prevented. Since electrolysis is a trouble peculiar largely to America the book, which is alone in its field, is very valuable. The translator has added a bibliography on the subject from 1895 to 1906 in English and foreign languages.

CONTENTS.—Chapter I.—Introduction. II.—Stray currents with Uniform Current Load on the Rails. III.—Stray Currents with Uniformly Increasing Current Load on the Rails. IV.—Resistance Values. V.—Distribution of Potential in the Earth. VI.—Corrosion Currents. VII.—Corrosion Currents which do not come from Railways. VIII.—Corrosion. IX.—Measurements. X.—Preventive Measures. XI.—Other Disturbances Caused by Stray Currents. XII.—Conclusions. Bibliography.

WIRELESS TELEGRAPHY. A book embodying a short history of Wireless Telegraphy, its theory, experiments and results attained. By A. Frederick Collins. 300 pages and 332 illustrations. New York, McGraw Publishing Co. Price, $3 net.

Chapter I.—Ether. II.—Wave Motion. III.—Electric Waves. IV.—Electric Oscillations. V.—Disruptive Discharge. VI.—Inductance. Capacity and Resistance. VII.—Oscillators. VIII.—Induction. IX.—Induction Coils. X.—Vibrators. XI.—Oscillating Current Generators. XII.—Electric Wave Action. XIII.—Electric Wave Detectors. XIV.—Transmitters. XV.—Receivers. XVI.—Auxiliary Apparatus. XVII.—Aerial Wires and Earths. XVIII.—Resonance. XIX.—Syntonization. XX—Wireless Telephony.

THE ELECTRIC TELEPHONE. A description of the construction and mechanism of the Electric Telephone. By Edwin J. Houston and A. E. Kennelly. Second edition. 454 pages, 151 illustrations. New York, McGraw Publishing Co. Price, $1 net.

Chapter I.—Introductory. II.—Elementary Acoustic Principles. III.—Elementary Electrical Principles. IV.—The Telephone Receiver. V.—The Microphone Transmitter. VI.—The Induction Coil. VII.—Call Bells and Batteries. VIII.—Single-Circuit Connections. IX.—Multiple-Circuit Connections. X.—Isolated Station Switchboards. XI.—Multiple Switchboards. XII.—Telephonic Circuits. XIII.—

Long-Distance Telephony. XIV.—Radiophony and Miscellaneous Applications of Electricity. XV.—Common Battery Systems. XVI.—Visual Signals. XVII.—Loaded Telephone Circuits.

REPORT OF THE ELECTRIC RAILWAY TEST COMMISSION TO THE PRESIDENT OF THE LOUISIANA PURCHASE EXPOSITION. Members of the Commission: J. G. White, Chairman; Geo. F. McCulloch, H. H. Vreeland, James H. McGraw, W. J. Wilgus. Report edited by Prof. H. H. Norris, Cornell University, and Bernard V. Swenson, Secretary of the American Street and Interurban Railway Association. Cloth, 621 pages, 4 folding plates. 209 illustrations. 102 tables. New York, McGraw Publishing Co. Price, $6 net.

There were sixty-one tests made, most of them at the Louisiana Purchase Exposition, and these cover every department of railway work. This book makes an excellent manual on Railway Work.

CONTENTS.—Introduction. Chapter I.—Service Tests of Electric Cars. II. Service Tests of Single-Truck City Car. III.—Service Tests of a Double-Truck City Car. IV.—Service Tests of an Interurban Car. V.—Acceleration Tests of a Single-Truck City Car. VI.—Acceleration Tests of an Interurban Car. VII.—Compressor Station Tests of a Storage Air System of Braking. VIII.—Braking Tests on a Double-Truck City Car Equipped with Air Brakes. IX.—Braking Tests on an Interurban Car Equipped with Air Brakes. X.—Braking Tests on a Single-Truck City Car Equipped with Magnetic Brakes. XI.—Tests of a Storage Battery Industrial Locomotive. XII.—Alternating Current Losses in Steel Rails and in Other Steel and Iron Sections. XIII.—Alternating Current Losses in Track. XIV.—Train Resistance Tests of Interurban Cars. XV.—The Test Car "Louisiana." XVI.—Air Resistance Tests. Appendix.—A. General Data Relating to Electric Cars. B. Acknowledgments.

ELECTRIC RAILWAYS. A series of papers and discussions presented at the International Electrical Congress in St. Louis, 1904. Cloth, 447 pages, illustrated. New York, McGraw Publishing Co. Price, $3 net.

CONTENTS.—The History of the Development of Electric Railways, Frank J. Sprague.

Some Early Work in Polyphase and Single-Phase Electric Traction, B. J. Arnold.

Electric Traction on British Railways, Philip Dawson.

The Monorail Railway, F. B. Behr.

The Electrification of Steam Railroads, B. J. Arnold.

Alternating vs. Direct-Current Traction, Dr. F. Niethammer.

Notes on Equipment of the Wilkesbarre & Hazleton Railway, Lewis B. Stillwell.

Transmission and Distributing Problems Peculiar to the Single-Phase Railway, Paul M. Lincoln.

Protection and Control of Large High-Tension Alternating-Current Distribution Systems, G. N. Eastman.

Rotary Converters and Motor-Generator Sets, William C. L. Elgin.

The Booster Machine in Traction Service and Its Proper Regulation, Dr. Gustav Rasch.

Storage Batteries in Electric Railway Service, Justus B. Entz.

Electrolysis of Underground Conductors, Prof. G. F. Sever.

Braking High-Speed Trains, R. A. Parke.

Alternating-Current Motors, C. P. Steinmetz.

Single-Phase Motors, Max Deri.

Alternating-Current, Machines with Gramme Commutators, Marius Latour.

Single-Phase Railway Motors, Friedrich Eichberg.

Theory and Operation of the Repulsion Motor, O. S. Bragstadt.

Theory of the Compensated Repulsion Motor, Ernst Danielson

Synchronous and Other Multiple Telegraphs. Some methods of obtaining independent telegraph circuits on a single wire with and without synchronism. By Albert Cushing Crehore, Ph.D.. Associate of the American Institute of Electrical Engineers, and author of "Alternating Currents" (with F. Bedell). Cloth, 124 pages, 42 illustrations. New York, McGraw Publishing Co. Price, $2 net.

Contents.—Part I.—Methods of Obtaining Independent Telegraph Circuits by the Use of Direct and Alternating Currents on the Same Wire. Introduction. Chapter I.—Receiving Apparatus in the Duplex-diplex System II.—Transmitting Apparatus in the Duplex-diplex System. III.—Applications of the Duplex-diplex System. IV.—Alternating and Direct Current Quadruplex. V.—Low Frequency Duplex-diplex.

Part II.—Methods of Obtaining Synchronism at Distant Points. Introduction. Chapter VI.—The Operation of Synchronous Motors on Wires which are used for no Other Purpose. VII.—The Operation of Synchronous Motors on Wires which are also used for Telegraphs.

Part III.—Synchronous Telegraphs. Introduction. Chapter VIII.—Measurements in Synchronous Telegraph Circuits. IX.—Explanation of the Measurements. X.—Different Conditions of Instruments and Line Leakage. XI.—Working in Opposite Directions on the Same Line. XII.—Morse Circuits: General Consideration and Particular Systems. Index.

The Electric Telegraph. A simple treatment of the methods employed in duplex, quadruplex and multiplex telegraphy. By Edwin J. Houston and A. E. Kennelly. Second edition. 480 pages, 172 illustrations. New York, McGraw Publishing Co. Price, $1 net.

Chapter I.—Introductory. II.—Elementary Electrical Principles. III.—Elementary Principles of Magnetism. IV.—Brief History. V.—The Simple Telegraph Circuit. VI.—Batteries and Dynamos. VII.—Relays. VIII.—Line Construction. IX.—Line Construction. X.—Repeaters. XI.—High-Speed Telegraphy. XII.—Duplex Telegraphy. XIII.—Quadruplex. XIV.—Multiplex, Printing and Fac-simile Telegraphy. XV.—Time and Train Telegraphy. XVI.—Electric Annunciators and Alarms. XVII. — Submarine Telegraphy. XVIII.—Operation and Maintenance of Cables. XIX.—Signaling without Wires.

The Induction Motor. A book covering the calculation, predetermination, design and general theory of the induction motor. By B. A. Behrend. 105 pages, 56 illustrations. New York, McGraw Publishing Co. Price, $1.50 net.

Chapter I.—The General Alternating Current Transformer. II. A.—The Character of the Magnetic Field in the Polyphase Motor. II. B.—The Formula for the Three-Phase Motor. III.—The Short-Circuit Current and the Leakage Factor. IV.—The Leakage Factor. V.—Design of a Three-Phase Current Motor for 200 Horse-power. VI.—The Single-Phase Motor. VII.—Calculation of a Single-Phase Motor. VIII.—The Polar Diagram of the General Alternating-Current Transformer Appendix I, II, III.

Electric and Magnetic Measurements and Measuring Instruments. By Frank W. Roller, M.E Cloth, 404 pages, 312 illustrations. New York, McGraw Publishing Co. Price, $3.50 net.

Contents.—Part I.—Chapter I.—Definition of Units. II.—Laboratory and Commercial Standards of Resistance, Current, E.M.F. Capacity and Inductance. III.—Galvanometers. IV.—Potentiometers. V.—The Measurement of Resistance. VI.—Current. VII.—Potentials. VIII.—Power. IX.—Capacity. X.—Inductance. XI.—Miscellaneous Determinations. XII.—The Location of Faults.

Part II.—Chapter I.—Recording Instruments. II.—Integrating Meters. III.—Maximum Demand Meters.

Part III.—Chapter I.—Magnetic Units. II.—Measurements of Field Strength. III.—Measurement of Permeability. IV.—Hysteresis. Appendix.

THE WIRING HANDBOOK. With 32 complete labor-saving tables and digest of underwriters' rules. By Cecil P. Poole. 85 pages. Illustrated. Flexible leather cover, pocket size. New York, McGraw Publishing Co. Price, $1 net.

CONTENTS.—Wiring Terms and Measurements of Feeders and Mains. Determining Wire Sizes. Three-Wire Circuits. Direct-Current Motor Wiring. Alternating Current Wiring. Determining the Size of the Bus-bar Conductors. Circuit Connections. Appendices. I.—Digest of the Underwriters' Rules Applying to Inside Wiring. II.—Fundamental Formulas.

DESIGNS FOR SMALL DYNAMOS AND MOTORS. Containing numerous designs for home construction of small dynamos and motors. Edited by Cecil P. Poole, from articles written for the *American Electrician*, many of which were published in the book entitled "Electrical Designs," which is now out of print. Cloth, 186 pages, 231 illustrations. New York, McGraw Publishing Co. Price, $2 net.

CONTENTS. — I. — One-sixth Horse-power Motor with Drum Armature. II.—One-sixth Horse-power Motor with Ring Armature. III. — One-fourth Horse-power Motor with Drum Armature. IV.—One-fourth Horse-power Motor with Ring Armature. V.—One-half Horse-power Motor with Drum Armature. VI.—One Horse-power Bipolar Motor, with Drum Armature. VII.—One Horse-power Four-polar Motor with Drum Armature. VIII.—Two Horse-power Four-polar Motor with Two-path Drum Armature. IX.—Three Horse-power Motor. X.—Direct-Current 110-Volt Fan Motor. XI.—Three Horse-power Launch Motor. XII.—Multipolar 35-Light Incandescent Dynamo. XIII.—A 75-Light Incandescent Dynamo. XIV.—400-Ampere Electroplating Dynamo. XV.—A 100-Ampere Electroplating Dynamo. XVI.—Self-starting Single-phase Induction Motor of One-half Horse-power. XVII.—One Horse-power Self-starting Single-phase Induction Motor. XVIII. Two Horse-power Self-starting Single-phase Induction Motor. XIX.—One Kilowatt Combined Alternating and Direct-Current Machine. XX.—Two Kilowatt Combined Alternating and Direct-Current Machine. XXI.—Four Kilowatt Combined Alternating and Direct-Current Machine. XXII.—Single-Phase Rectifier.

ELECTRIC POWER TRANSMISSION. A complete treatise on the practical and commercial side of electric power transmission. By Louis Bell, Ph.D. Fourth edition, thoroughly revised and greatly enlarged. 729 pages and 341 illustrations, 25 plates. New York, McGraw Publishing Co. Price, $4 net.

Chapter I.—Elementary Principles. II.—General Conditions of Power Transmission. III.—Power Transmission by Continuous Currents. IV.—Some Properties of Alternating Currents. V.—Power Transmission by Alternating Currents. VI.—Alternating Motors. VII.—Current Reorganizers. VIII.—Engines and Boilers. IX.—Water Wheels. X.—Hydraulic Development. XI.—The Organization of a Power Station. XII.—Secondary Apparatus. XIII.—The Line. XIV.—Line Construction. XV.—Distributing Systems. XVI.—The Commercial Problem. XVII The Measurement of Electrical Energy. XVIII.—Present Tendencies in High-voltage Transmission.

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A paper presented at the 213th meeting of the American Institute of Electrical Engineers, New York, January 25, 1907.

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(*Subject to final revision for the Transactions.*)

ON THE SUBSTITUTION OF THE ELECTRIC MOTOR FOR THE STEAM LOCOMOTIVE.

BY LEWIS B. STILLWELL AND HENRY ST. CLAIR PUTNAM.

The purpose of this paper is fourfold: 1, to record certain facts relative to heavy electric traction which have been established by experience; 2, to present calculations of relative costs of steam and electric traction in railway service based upon these facts; 3, to point out the transcendent importance of standardizing electric railway traction equipment as rapidly as may be consistent with progress; and 4, to raise the question whether a frequency of 25 cycles per second or 15 cycles per second should be adopted in railway operation by alternating-current motors.

Few subjects which are to-day engaging the attention of the engineering world are comparable either in scientific interest or in practical importance to the substitution of the electric motor for the steam locomotive engine. Three-phase and single-phase alternating-current railway motors are now developed to a point where they fairly challenge the steam locomotive, even in long-haul freight service, in which class of work the direct-current motor hitherto has found itself unable to compete with success. The direct-current motor has demonstrated impressively, and upon a large scale, its superiority to the steam locomotive, not only in operating single cars and short trains on lines of moderate length, but also in frequent and heavy passenger service in which the length of train is limited only by the length of station platform, while the motive power equipment far exceeds in power developed the limits hitherto established in steam passenger service.

On the Valtellina line and through the Simplon tunnel 70-ton

TO VIMU AMMOTLIAO

electric locomotives with three-phase motor equipment, capable of developing a draw-bar pull of 28,000 lb., have displaced the steam locomotive, with results showing both marked improvement in service and substantial economy in operating costs. In the New York Subway, eight-car trains weighing 320 tons are in operation, equipped with motors developing during acceleration a tractive effort equivalent to a draw-bar pull of 55,000 lb.

The heaviest passenger locomotive used on the Erie system, weighs, exclusive of tender, 206,000 lb., of which 55.8%, or 115,000 lb., is effective on drivers. Assuming the adhesion to be 20%, such a locomotive exerts a draw-bar pull of 23,000 lb. The motors of the eight-car electric train of the New York Subway, therefore, exert a tractive effort equivalent to more than twice the draw-bar pull of this locomotive.

Managers and engineers of railways using steam are considering the possibilities of electricity. Naturally, the problem usually presents itself in reference to particular cases in which special conditions emphasize the advantages of electric traction; but a point has been reached in the development of electric railway equipment where it is evident that no absolute and permanent limits beyond which the motor may not go can be fixed; and it is not unreasonable to consider the possibilities of the electric motor not only in passenger service but also in freight service, not only in the operation of railway terminals, but also for the operation of railway divisions and even for trunk lines.

At the present time, what is needed is not prophecy but facts, and particularly facts demonstrated by experience. A study of the relative advantages of steam and electric traction should rest as firmly as possible upon results attained in practical operation. Facts thus established and available to date are insufficient to justify conclusions which in detail may not have to be modified, but it is believed that they are adequate to permit comparative studies leading to deductions, which, as a whole, may be relied upon.

The answer to the question: "Will it pay to electrify?" involves consideration of both relative earnings and relative cost of operation; therefore, before discussing the comparative expenses involved, it is pertinent to refer briefly, even at the risk of repeating what has been said in papers hitherto presented by others, to the more important factors which cooperate in securing for electric traction an increase in earning power.

PASSENGER SERVICE FACTORS CONTRIBUTING TO INCREASED EARNING POWER.

The more important considerations which affect gross earnings are:

1. Frequency of service.
2. Speed.
3. General comfort of passengers.
4. Safety.
5. Reliability of service.
6. Increased capacity of line.
7. Frequency of stops.
8. Convenient establishment of feeder lines.

1. *Frequency of Service.* The motor-driven, interurban car operating upon scores of lines in competition with steam railway service has convincingly demonstrated its ability, not only to attract business from competing steam lines but also to create new business. In almost every case where such competition has been encountered by the steam railway, a large part, if not practically all of its local passenger traffic has been lost. In comparing results attained by the competing systems in such cases, it is impossible, of course, to state in terms of precision how far frequency of service is responsible for the remarkable results observed, since to these results a number of other causes also contribute. But without attempting to differentiate between these various factors, it is sufficient here to say that of the several causes contributing to the marked success of lines using electricity, the operation of train units or of single cars upon close headway is recognized to be especially attractive.

The advantages resulting from frequency of service become relatively less as the length of run is increased. It is recognized, however, that the operation of trains under close headway generally increases traffic, even where the haul is of considerable length, as shown by the experience of the Philadelphia & Reading Railroad in operating its fast trains upon one-hour headway between New York and Philadelphia.

2. *Speed:* The possibilities of operating by electricity at speeds exceeding the maximum which can be obtained safely in steam operation, owing to the elimination of unbalanced reciprocating

parts of the locomotive, is well-known. It was strikingly illustrated in the Berlin-Zossen trials by the attainment of a speed exceeding 130 miles an hour. These tests demonstrated the ability of electric equipment to operate at a sustained speed more than twice as great as that of our fastest express trains on runs of any considerable length, and exceeding by about 50% the maximum which can be attained even for a short distance by the steam locomotive with a reasonable degree of safety.

Even at speeds at which steam locomotives may be operated without great danger of leaving the track, as a result of the effect of unbalanced reciprocating parts, electric engines are far better able to maintain speed while drawing heavy trains. At speeds of 80 or 90 miles an hour, for example, it is extremely difficult to operate with satisfactory results two steam locomotives at the head of the train; while multiple-unit control places any necessary number of locomotive units absolutely and instantly responsive to the will and touch of a single operator. At high speeds, also, the economy of the steam locomotive falls off rapidly while that of its competitor remains practically constant.

The increase in average speed resulting from the relatively high acceleration obtainable in the use of multiple-unit electric equipment in service where stations are very close together; *e.g.*, elevated and subway lines in cities, and in suburban service in the vicinity of large cities, has been frequently discussed from the theoretical standpoint and is well understood.

3. *General Comfort of Passengers:* The great advantages of electric traction in respect to comfort of passengers are well-known. Cleanliness and improved ventilation made possible by the elimination of smoke and cinders; lighting practically without heat and at low cost by a system which makes it easy to place lamps in any desired location, and heating apparatus effectively and conveniently controlled, are factors of very great importance in building up passenger business under conditions of competition. In operating through tunnels, ventilated with difficulty, the electric motor, in eliminating smoke and the gases of combustion, possesses an advantage which is frequently controlling.

4. *Safety:* So much has been said and printed in the daily press regarding the alleged dangers of electric traction, that it is well to place on record here a statement of the considera-

tions which inevitably lead to the conclusion that electric traction, if the equipment be properly designed and installed, is essentially and materially safer, so far as the traveling public is concerned, than steam traction. The more important of these considerations are:

a. The fact that in case of a rear-end collision, which is perhaps the most frequent form of accident experienced in the operation of our railway systems, the energy which propels the electric train can be shut off generally with great promptness. On the other hand, the steam locomotive carrying in its fire-box from 1500 to 2000 lb. of coal heated to incandescence, almost invariably sets fire to any broken cars, or other combustible material with which it comes in contact. Where the electric supply to trains is obtained at low potential from a third rail, the risk of short circuit, which may result in fire if the cars be not fireproof, is greater than it is in the case of overhead construction, even when the voltage employed in the latter case is very high. In fact, in the latter case it may be said that risk from the physiological effects of the current or from fire resulting from short circuit, is practically eliminated, except perhaps in tunnels of very limited clearance.

b. The elimination of the boiler carrying steam at high pressure, also means the removal of an element of risk which in many railroad accidents has destroyed life.

c. The absence of smoke in tunnels, and consequent ability to see signals clearly at all times, constitutes an advantage ot the utmost importance for electric operation.

d. Cars drawn by steam locomotives must be heated either by steam from the locomotives, or by some form of stove carried on the individual cars. In the former case, steam from broken steam pipes becomes a serious source of danger in case of accident; in the latter the hot coals from the stove, even in the improved modern types which have greatly reduced the risk formerly encountered, are a source of danger. The substitution of the electric heater affords opportunity not only for ideal control of temperature of the cars but almost absolutely eliminates risk of fire.

e. The elimination of the gas tank and the oil lamp used for lighting in steam traction, and the substitution of electric lighting, also implies a material gain in safety.

f. The danger of derailment in the case of the electric locomotive is far less than in case of the steam locomotive, by reason of the elimination of unbalanced reciprocating parts which tend to lift the steam locomotive from the tracks. The hammer-blow also, in the case of the steam locomotive, is responsible not infrequently in cold weather for broken rails, as a direct result of which many serious accidents have occurred.

g. The electrification of railways where high-speed passenger traffic is involved, affords opportunity for improved methods of protecting trains by signal systems, automatic or other.

h. The ability to cut off power at will from a given section and therefore from trains operating upon that section under certain conditions, which arise not infrequently in railway service, may be availed of to prevent accidents. In steam railway service, when an operator at a tower having allowed a train to pass learns too late that another train is approaching in the opposite direction, he is powerless to avert the impending collision. Where the motive power of these trains, however, is transmitted by electricity, the power supplied to the section might be cut off and probably in time to prevent the catastrophe.

As against the considerations above referred to, all of which tend to make electric operation safer than operation by steam locomotive, the addition to the permanent way equipment of an electric conductor conveying power to trains imposes in the former case a material risk not involved in the latter. If the power be supplied through a third rail, a guard should be used whenever possible to prevent accidental contact with the rail by employes or by others walking upon or crossing the track. Several effective forms of guard are available, of which at least one has been in service upon a convincing scale for five years.

5. *Reliability of Train Service:* Interesting evidence in respect to the relative reliability of steam locomotives, and of electric motors carried upon cars and controlled by the multiple-unit system of train-control, is derived from the official records of the transportation department of the Manhattan Division of the Interborough Rapid Transit system of New York. Upon the elevated lines, steam locomotives were used from the inauguration of the first constituent line of the ultimate system in 1872 until 1902, during which year and a part of the following year, electric equipment was gradually substituted. The locomotives were operated under exceptionally favorable conditions, were not overloaded, were of simple construction, and admirably maintained. The electric equipment that succeeded them is operating trains which average

5.3 cars as against 3.8 cars in the days of steam operation. The average speed is materially higher. The tractive effort during acceleration of a six-car train is 30,000 lb. as against a maximum draw-bar pull of approximately 7,000 lb. exerted by the steam locomotive.

Accurate record is kept of the duration of every delay in the operation of the trains. The results for the months November 1900 to March 1901, when steam was used, and the corresponding months of the years 1905-6 under conditions of electric operation, illustrate in a striking manner the marked gain in reliability of service which has resulted from the adoption of electricity. For the five months of steam operation the aggregate car-mileage was 18,527,773 miles, and the aggregate delay 8258 train minutes. The car-mileage per train-minute delay was 2243.

For the corresponding period of electric operation, 5 years later, the car-mileage was 25,482,081, the aggregate train-minutes' delay 5970 and the car-mileage per train-minute delay was 4268.

It will be noted that the months involved in the above comparison are those in which the difficulties of operation, owing to weather conditions and number of passengers transported are at a maximum. Snow and sleet are among the greatest difficulties to be overcome in the operation of a third-rail system, when, as in the case of the Manhattan, the third rail cannot be effectively protected by reason of limitations in space available on the stucture. In view of these difficulties and of the increase in density of traffic, the results obtained are remarkable.

6. *Increased Capacity of Line.* Electric traction as compared with steam traction enables us to develop much greater sustained tractive efforts with given weight on drivers, by reason of more uniform rotative effort. Even where electric locomotives are used, it also eliminates dead weight by abolishing the tender and facilitating construction under which practically the entire weight of the locomotive is carried upon the drivers. Where the locomotive is dispensed with, and the motors mounted directly upon trucks of cars constituting the train, the best results are obtained, the proportion of weight upon wheels driven by motive power being greater than is otherwise practicable. This increase in weight available for adhesion, in conjunction with the characteristics of the electric motor, makes it possible to attain in electric service rates of accelera-

tion altogether impracticable in steam service; consequently trains in passenger service where short headway is desirable can follow each other at shorter intervals than is feasible where steam motive power equipment is employed.

In the operation of freight trains, if it should ever become practicable to distribute electric locomotives throughout the length of the train and operate them by multiple-unit control, trains of length far beyond present limits could be operated. At present, the length of a freight train is limited by the strength of the draft-gear, and steam locomotives cannot advantageously be distributed at intervals throughout a very long train, as no means is available for controlling their effort simultaneously and satisfactorily.

Obviously, a system permitting distribution of the motive power at convenient intervals throughout the train, and simultaneously controlled by the hand of a single engineman, presents possibilities of increasing track capacity which under conditions now existing on many through lines should be of great value.

7. *Frequency of Stops:* The interurban electric line competing with the steam railroad for traffic between two cities possesses great advantage in the collection and distribution of passengers, from the ability of its cars to stop at any street intersection or other convenient point, instead of receiving and discharging passengers at a single railway station in each town. These frequent stops, however, operate to reduce speed materially, and but for the ability of the electric equipment to accelerate rapidly the limitation would be very serious. As speed between terminals is increased, the tendency to reduce the number of stops made to take on or let off passengers is noticeable in the development of many interurban lines.

8. *Convenient Establishment of Feeder Lines:* Frequency of stops for convenient collection and distribution of passengers, and high speed between terminals, being considerations which are essentially opposed, the advantages of a four-track system permitting operation of local or collecting train units on two tracks, and express trains on the other two tracks, are obvious. The great expense of such a system, however, can be borne only where traffic is very heavy.

A natural development which during the last five years has been very rapid, is found in the use of comparatively short electric trolley lines in connection with steam express service for long-distance runs. This method of utilizing the advantages of local electric lines by the companies operating trunk line systems is eminently wise, and in general should be highly advantageous to the properties concerned while increasing materially the facilities offered to the public. It may be pointed out, however, that were the trunk line systems to utilize electricity for through traffic, the extension and systematic improvement of local feeders would be facilitated for a number of reasons, notably:

1. The fact that power developed in large amount, as for the operation of heavy through traffic, is produced at low cost per unit, and would be available at all points along the line for the operation of cars on local feeder lines.

2. The convenient possibility of attaching cars or short trains arriving on local lines to through trains at points of junction. The multiple-unit system of car equipment lends itself admirably to this method of operation.

ILLUSTRATIONS OF PASSENGER BUSINESS DEVELOPED BY INTERURBAN ELECTRIC LINES.

In a very comprehensive paper presented by Mr. J. G. White before the International Engineering Congress at St. Louis in 1904, the following striking illustrations of the advantages of frequent service are given:

"*Cleveland-Oberlin Line.* These cities are 34 miles apart. The competitors for passenger traffic between these cities and intermediate points are the Lake Shore & Michigan Southern Railroad (steam) and the Cleveland, Elyria & Western (electric). In 1895 the total number of passengers carried by the steam railway between these cities and intermediate points was 203,014. This total decreased gradually after the competing electric line was opened to a minimum in 1899 of 71,755, from which it gradually recovered in 1902 to 91,761, but during this same year the electric road carried a total of about 3,000,000.

"*Cleveland-Painesville Line.* These cities are 39 miles apart. The competitors for passenger traffic are the Lake Shore (steam) and the Cleveland-Painesville & Eastern Railway (electric). In 1895 the steam road carried between the terminals and intermediate points 199,292 passengers, but in 1902 it carried only 28,708 passengers, while the electric system carried 1,537,754 passengers.

"*Cleveland-Lorain Line.* These cities are 26 miles apart.

Competitors are the New York, Chicago & St. Louis Railroad (steam) and the Lake Shore (electric). In 1895 the steam road carried 42,526 passengers but in 1902 it carried only 9,795 passengers, the electric road in the same year carrying 3,896,902 passengers."

The Lackawanna & Wyoming Valley Railway Company, operating a double track system between the cities of Scranton and Wilkes-Barre, Pa., carried, during the four months ending October 1906, 1,396,833 passengers. This railway, 18 miles in length, competes with two double-track steam railways having excellent terminals in both cities, and with a third double-track steam railway having an equally good terminal in Scranton, but a less favorably located terminal at the Wilkes-Barre end of the line. The electric railway charges 30 cents for the ride between the two cities and sells round-trip tickets for 50 cents. Except at certain hours, it operates its service upon 10 minutes' headway. At least one of the steam railways, in the endeavor to retain its passenger business, has reduced its rate to 40 cents for the round trip. It has also increased the frequency of its train service. We have been unable to ascertain the number of passengers carried by the competing steam lines during the four months above referred to, but the earning power of frequent electric service is strikingly demonstrated by the fact that this railroad, operating in competition with three double-track steam railways of practically identical length and substantially equal terminal facilities, should be doing a business which represents an income of $5.00 per capita per annum of tributary population, including that of the terminal cities.

ELECTRIFICATION OF TRANSPORTATION SYSTEMS IN MANHATTAN AND THE BRONX—EFFECT UPON TRAFFIC

A study of the transportation statistics of New York City, particularly during the last decade, is not only of great local interest, but is instructive as illustrating the effect of improvement in transit facilities upon gross receipts.

The data graphically summarized in Figs. 1, 2, and 3 have been compiled from official records; those subsequent to June 30, 1883, being obtained from the reports of the Railroad Commission of the State of New York. The effects of improved service are clearly evident from an inspection of these figures.

In Fig. 1, the line marked "All lines" indicates for each year ending June 30, the aggregate paid fares collected by all surface, elevated, and subway lines in the Boroughs of Manhattan and Bronx. It will be noticed that the aggregate paid fares for the year ending June 30, 1894, and also for the following year, were slightly less than for the year ending June 30, 1893. this reduction doubtless being due to the hard times which then prevailed. With this exception, the aggregate of paid fares for all lines shows in each year an increase over the preceding year. Comparing the Manhattan System for the year 1893 with the same system for the year 1899, a decrease of 21% in paid fares is shown. During the same period the paid fares of surface lines, which meanwhile in large degree had adopted electric operation, increased by 43%. That the decrease in

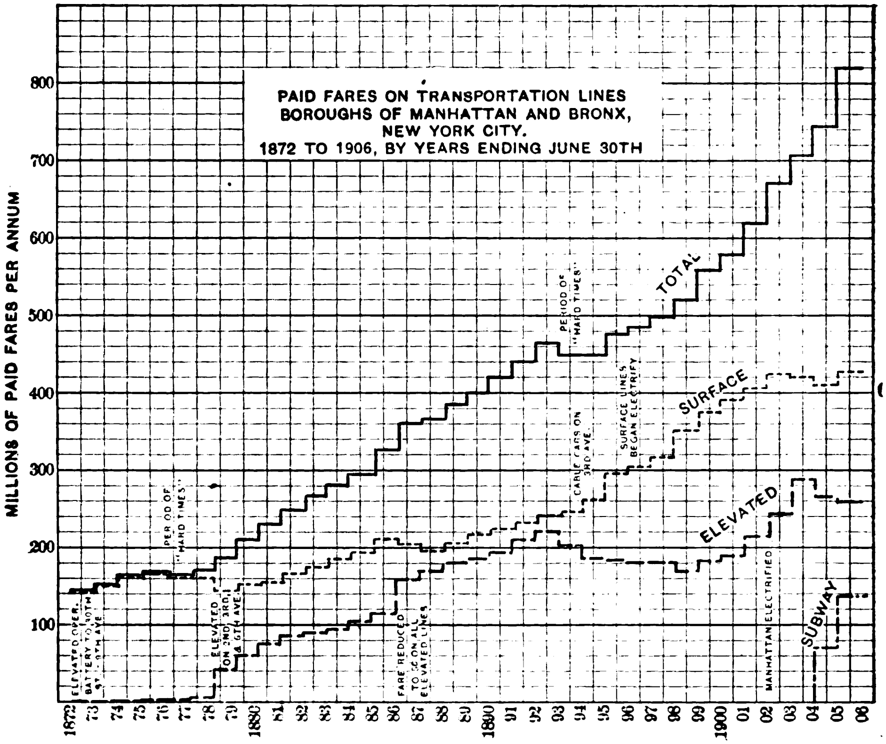

FIG. 1.

business on the elevated lines was not due to any decrease in the service, is shown by Fig. 2, from which it will be seen that the car mileage operated increased steadily during this period. The unavoidable inference is that the diversion of traffic to the surface lines was a direct result of the improved service offered by the latter.

During the year ending June 30, 1901, the last fiscal year of steam operation on the elevated lines, the Manhattan system collected 190,045,741 fares. The surface lines collected 388,108,794 fares. During the year ending June 30, 1904, the Manhattan System, now operated by electricity, collected 286,634,195 fares, an increase of 50%, while the surface lines collected 419,423,092, an increase of about 8%. In the following year, 1904, the subway began operation, and both elevated and surface lines recorded a decrease in fares collected.

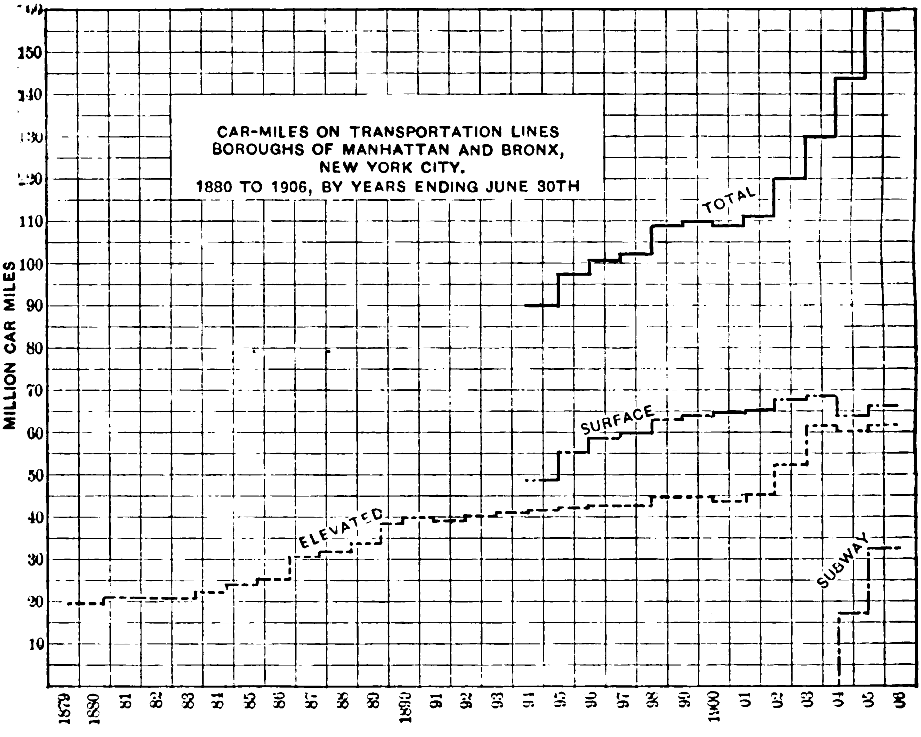

FIG. 2.

In Fig. 4 are plotted curves showing the population of, *a*, Greater New York and, *b*, the Boroughs of Manhattan and the Bronx. The points which fix these curves from 1860 to 1900

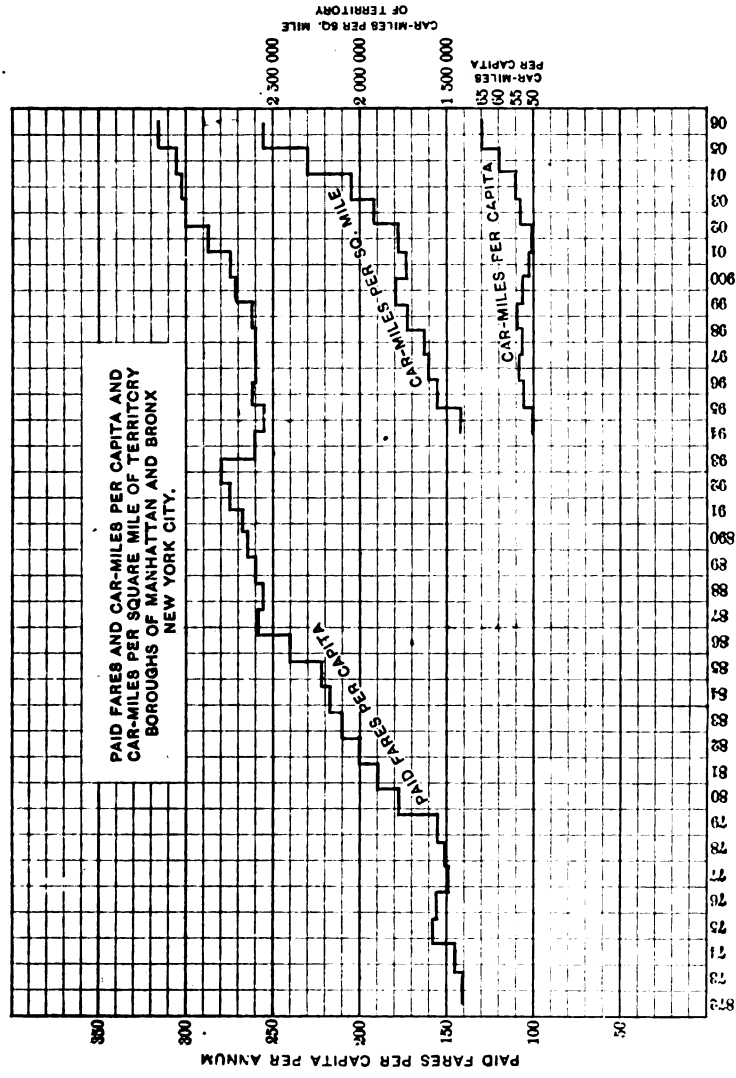

FIG. 3.

inclusive, are from the United States Census Reports. For the years 1910 and 1920 the estimated population is based upon the average rate of change in the per cent. increase per

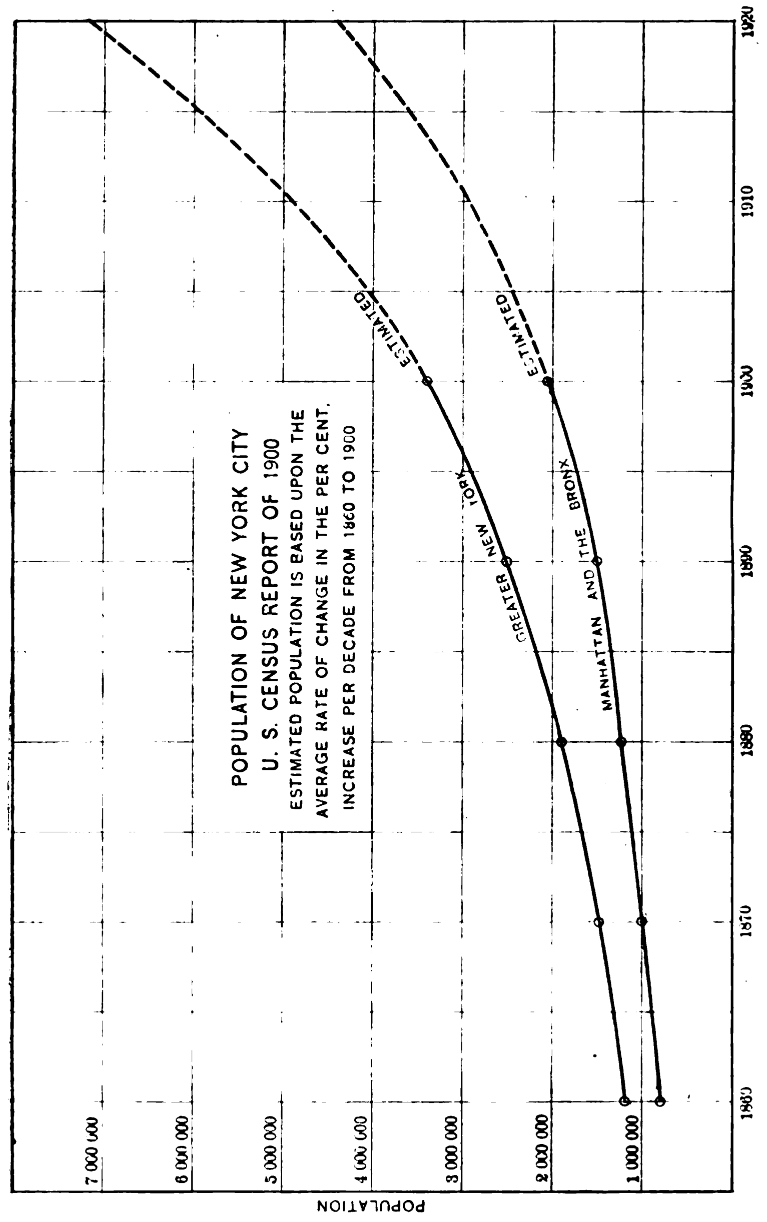
POPULATION OF NEW YORK CITY
U. S. CENSUS REPORT OF 1900
ESTIMATED POPULATION IS BASED UPON THE
AVERAGE RATE OF CHANGE IN THE PER CENT.
INCREASE PER DECADE FROM 1860 TO 1900
ESTIMATED
ESTIMATED
GREATER NEW YORK
MANHATTAN AND THE BRONX
7 000 000
6 000 000
5 000 000
4 000 000
3 000 000
2 000 000
1 000 000
POPULATION
1860
1870
1880
1890
1900
1910
1920

Fig. 4.

decade from 1860 to 1900. Up to 1905, the population as indicated in these curves is undoubtedly not far from the fact; for 1910 and 1920 the probable populations indicated are interesting, although the curves take no account of the effect of improved transit facilities between Manhattan and Long Island, and between Manhattan and New Jersey.

Notwithstanding the very rapid increase in population of the Boroughs of Manhattan and Bronx from 1890 to 1905, the paid fares collected by the several transportation systems have increased still more rapidly, as shown in the curve of paid fares per capita in Fig. 3.

In the same figure are shown the increase in car-miles per capita per annum, and in car-miles per annum per square mile of territory served.

While it is not directly pertinent to this discussion, we would here call attention to a fact of great importance to those responsible for the development of the systems of transportation in the City of New York; viz., the fact that while for the year ending June 30, 1906, the subway carried 137,919,632 passengers, the aggregate carried by the elevated and surface lines was but 23,684,957 less than the aggregate carried by these lines during the year ending June 30, 1904, the last fiscal year before the subway began operation. In other words, comparing the year 1906 with 1904, the aggregate paid fares on elevated, surface, and subway lines, increased by 114,234,675, which is about three-fourths the ultimate capacity of the present subway. It is evident from inspection of these curves, that the existing systems are destined to be still further and greatly overcrowded before additional subways can be completed.

It is of course impracticable in studying the results of improved service in the electrification of elevated, surface, and subway lines in New York, to attempt to differentiate the causes which have contributed to the increased traffic. While that increase has been due undoubtedly in large part to the improved service offered, it is also obvious that the number of passengers carried would have increased very materially by the growth of population, even had no improvement in the old conditions of service been effected. But it cannot be too strongly emphasized, that while from one point of view improved transit facilities are a result of increased population, from another and equally tenable point of view, increased population is a result of improved transit facilities.

COMPARATIVE COSTS OF OPERATION.

As the standard with which to compare our estimates of cost of electric operation, we have adopted the grand average results obtained in operation by steam locomotives upon the existing railways of the United States, as set forth in the report of Statistics of Railways for 1904 compiled by the Interstate Commerce Commission, and proof-sheets of the report of the Commission for the year 1905. We shall follow the classification of operating expenses adopted by the commission, and generally used by the railroad companies in their annual reports. The estimated costs of electric operation being approximately determined as compared with the grand averages obtaining in steam railroad practice in this country, the work of determining, for any given case, the relative advantages and disadvantages of steam and electric operation will perhaps be facilitated. We compare, of course, the itemized operating expenses in the case of operation by electricity with corresponding expenses under existing conditions of steam motive power equipment. In estimating operating expenses of electric equipment, we have based conclusions upon results obtained in practice so far as we possess the necessary data.

The substitution of electric for steam equipment involves a large investment in power plant, and in electric conductors and apparatus for conveying power from the power plant to the moving trains, The distributing system for alternating-current equipment, which is the only class of equipment deserving serious consideration in connection with the general problem which we are discussing, comprises an addition to permanent way equipment in the form of overhead construction and electrical conductors conveying power from the power house to the trolley or conductor which is carried above the track. At the present time, the limit of potential generally adopted in this country in constructing alternating-current dynamos is 11,000 volts. Where this voltage is generated, and the distance from the power house to the section of railroad to be electrified does not exceed 25 or 30 miles, step-up and step-down transformers are unnecessary. For greater distances, higher potentials are used upon the feeder circuits between power house and trolley, transformers for increasing the generated potential being installed in the power house, and transformers for lowering the potential to that selected for the trolley; *e.g.*, 11,000 volts, being located in suitable transformer houses at intervals of from 30 to 50 miles, depending chiefly upon density of traffic.

For the trolley, a potential of 11,000 volts is suitable and can be adequately insulated. The mechanical support for the trolley comprises, preferably steel poles with brackets or light steel bridges spanning the track.

The cost of the power plant and distributing system are properly chargeable to capital account.

Our estimates are based upon the assumption that single-phase alternating-current equipment is used; that the trolley potential is 11,000 volts; that each power-house supplies railway line to a distance of 150 miles in each direction, the feeder potential employed being 60,000 volts; that the overhead construction is first class in every respect, and steel bridges and field poles set in concrete being exclusively used for the support of both trolley conductors and feeders.*

As regards equipment of the rolling stock, it is the general practice of our railways to charge against operating expenses all new equipment purchased to replace that which has been worn out in service. In the adoption of electricity, it would seem that this method might be followed in general by our more important railway systems, the substitution of electric equipment beginning naturally upon those parts of the system where the resulting advantages are maximum. In other words, worn-out locomotives, etc., on such a system might be replaced by electric equipment and the cost of the equipment charged against operation, just as the cost of new steam locomotives otherwise required would be charged against operation. For example, the Erie Railroad system, on June 30, 1906, had 1333 locomotives in service. Taking no account of increases necessitated by growth of the company's business, not less than 60 new locomotives should be added to this equipment each year to take the place of those worn out in service. The cost of these new locomotives under steam operation would be charged against "Repairs and renewals of locomotives," and it would seem that their value expended for electric equipment to replace them might be similarly charged. In addition to the purchase of new locomotives to replace those worn out in service, our railroads are compelled from year to year, by the growth of their business, to purchase additional locomotives and other rolling equipment. While these are usually charged against capital account in one form or another, it may be pointed out that any method of financing their cost which may be adopted is equally applicable to electric locomotives.

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*In assuming the use of the single-phase system we are not condemning other systems. The three-phase system has not received from American engineers in general, that degree of consideration which its possibilities and demonstrated advantages justify. Its use, at least on mountain-grade divisions, can be supported by very strong arguments.

In cases where the initial substitution of electricity is on a large scale, as compared with the total rolling stock equipment of the railroad making the change, it is probable that a part if not all of the cost of electric rolling stock equipment will generally be charged to capital account.

We proceed to compare the cost of electric operation with the cost of operation by steam locomotives, using as our standard of comparison the grand average results in steam operation in the United States for the years 1901–1905, inclusive. These average results are set forth in the following tables compiled from the reports of the Interstate Commerce Commission and printed on the three following pages. Many of the items included in this tabulation vary between wide limits in the practice of different railroads.

MAINTENANCE OF WAY AND STRUCTURES

Under the general heading, " Maintenance of Way and Structures," item No. 1, " Repairs of Roadway," if changed at all should show some reduction under conditions of electric operation, but obviously no material change is to be expected. We assume therefore that this item, amounting to 10.818% of total operating expenses, will remain unchanged.

The items, " Renewals of rails," " Renewals of ties," and " Repairs and renewals of bridges and culverts," may be conveniently grouped. In the aggregate, these on the average steam operated railroad amount to 6.33% of the total cost of operation. If the electric locomotive be substituted for the steam locomotive, it is safe to predict that this group of items of expense will be reduced; but it is practically impossible to state with accuracy what the reduction will amount to. In general, it is obvious that the substitution of electric locomotives developing equal draw-bar pull, with axle-loads reduced at least 25% as compared with steam locomotives, and with wheel-bases not exceeding those of steam locomotives, should favorably affect these items. From the best study which we have been able to make of the detailed factors comprised under these three items of the classification, it would seem that under

TABLE I

Item	Amount 1905	Per cent.					Average Five Years	Estimated Cost of operation by Electricity
		1905	1904	1903	1902	1901		
Maintenance of Way and Structures......	274,415,279	19.784	19.519	21.185	22.255	22.272	21.003	22.354
1. Repairs of roadway	144,161,701	10.393	10.348	11.093	11.331	10.294	10.818	10.818
2. Renewals of rails..	18,259,022	1.316	1.298	1.386	1.521	1.676	1.439	5.00
3. Renewals of ties...	36,856,864	2.657	2.519	2.487	2.838	3.140	2.728	
4. Repairs and renewals of bridges and culverts..........	32,166,990	2.319	2.228	2.461	2.593	2.730	2.466	
5. Repairs and renewals of fences, road-crossings, signs and cattle-guards.....	6,179,686	0.446	0.437	0.527	0.625	0.598	0.527	0.527
6. Repairs and renewals of buildings and fixtures..........	29,320,204	2.114	2.147	2.590	2.562	2.417	2.366	1.300
7. Repairs and renewals of docks and wharves..........	2,883,274	0.208	0.209	0.235	0.220	0.283	0.231	0.231
8. Repairs and renewals of telegraph...	2,374,932	0.171	0.179	0.165	0.173	0.158	0.169	0.169
9. Stationery and printing..........	383,158	0.028	0.029	0.032	0.031	0.029	0.030	0.030
10. Other expenses....	1,829,448	0.132	0.125	0.209	0.361	0.317	0.229	0.229
Repairs and renewals of track bonding.............								0.800
Repairs and renewals of overhead construction......								3.250
Maintenance of Equipment.............	288,012,604	20.765	19.967	19.133	19.127	18.629	19.524	12.287
11. Superintendence ..	7,831,965	0.565	0.567	0.559	0.601	0.599	0.578	0.578
12. Repairs and renewals of locomotives.	114,988,428	8.290	7.904	7.408	7.246	6.695	7.509	2.253
13. Repairs and renewals of passenger cars............	27,342,129	1.971	1.951	2.044	2.157	2.277	2.080	2.080
14. Repairs and renewals of freight cars.	113,723,239	8.199	7.777	7.442	7.432	7.436	7.657	6.000
15. Repairs and renewals of work cars.....	3,360,390	0.242	0.231	0.242	0.245	0.233	0.238	0.238
16. Repairs and renewals of marine equipment............	2,650,543	0.191	0.154	0.177	0.215	0.234	0.194	0.194
17. Repairs and renewals of shop machinery and tools.....	9,186,101	0.663	0.704	0.696	0.643	0.605	0.662	0.500
18. Stationery and printing..........	595,571	0.043	0.042	0.046	0.044	0.043	0.044	0.044
19. Other expenses....	8,334,240	0.601	0.637	0.519	0.544	0.507	0.562	0.400

Note.—It is customary with some railroads using electric equipment to include under the general heading "Maintenance of Equipment," the maintenance of the power plant and electric transmission systems. Both of these, however, are more conveniently treated by including them in the cost of electric power delivered to the overhead trolley system or third rail.

TABLE I.—*Continued.*

Item	Amount 1905	Per cent.					Average Five Years	Estimated Cost of operation by Electricity
		1905	1904	1903	1902	1901		
Conducting Transportation	769,613,017	55.486	56.670	55.893	54.671	54.979	55.540	43.454
20. Superintendence	25,007,322	1.803	1.779	1.742	1.711	1.726	1.752	1.752
21. Engine- and roundhouse men	130,437,844	9.404	9.550	9.562	9.401	9.340	9.451	4.710
22. Fuel for locomotives	156,429,245	11.278	12.128	11.675	10.776	10.602	11.292	5.553
23. Water supply for locomotives	9,147,590	0.660	0.659	0.614	0.623	0.612	0.634	0.000
24. Oil, tallow, and waste for locomotives	5,442,970	0.392	0.397	0.389	0.366	0.361	0.381	0.250
25. Other supplies for locomotives	3,295,384	0.238	0.248	0.232	0.218	0.206	0.228	0.228
26. Train service	90,654,520	6.536	6.735	6.677	6.737	7.011	6.739	6.739
27. Train supplies and expenses	21,963,086	1.583	1.581	1.552	1.500	1.471	1.537	1.000
28 Switchmen, flagmen and watchmen	60,141,422	4.336	4.386	4.313	3.984	3.848	4.173	4.173
29. Telegraph expenses	24,823,266	1.790	1.788	1.754	1.784	1.785	1.780	2.000
30. Station service	89,304,658	6.438	6.605	6.664	6.832	6.947	6.697	6.697
31. Station supplies	8,961,573	0.646	0.686	0.667	0.676	0.672	0.669	0.669
32. Switching charges, balance	4,201,050	0.303	0.280	0.244	0.272	0.319	0.284	0.284
33 .Car per diem and mileage, balance	18,835,325	1.358	1.358	1.400	1.480	1.618	1.423	1.423
34. Hire of equipment, balance	3,040,641	0.219	0.195	0.214	0.180	0.161	0.194	0.194
35. Loss and damage	19,782,692	1.426	1.279	1.094	0.990	0.819	1.112	0.750
36. Injuries to persons	16,034,727	1.156	1.196	1.120	1.048	0.911	1.086	1.000
37. Clearing wrecks	3,594,658	0.259	0.275	0.284	0.221	0.189	0.246	0.200
38. Operating marine equipment	9,903,479	0.714	0.696	0.745	0.721	0.862	0.748	0.748
39. Advertising	5,959,380	0.430	0.418	0.428	0.429	0.428	0.427	0.427
40. Outside agencies	19,688,261	1.419	1.411	1.449	1.579	1.615	1.495	1.495
41. Commissions	233,987	0.017	0.022	0.044	0.077	0.089	0.050	0.050
42. Stock yards and elevators	786,850	0.057	0.060	0.057	0.069	0.075	0.064	0.064
43. Rents of tracks, yards and terminals	23,947,881	1.727	1.563	1.544	1.519	1.724	1.615	1.615
44. Rents of building and other property	4,814,407	0.347	0.382	0.411	0.440	0.440	0.404	0.404
45. Stationery and printing	8,772,789	0.632	0.640	0.642	0.622	0.638	0.634	0.634
46. Other expenses	4,408,010	0.318	0.353	0.376	0.416	0.510	0.395	0.395

TABLE I.—*Continued.*

Item	Amount 1905	Per cent. 1905	1904	1903	1902	1901	Average Five Years	Estimated Cost of operation by Electricity
General Expenses.....	55,022,127	3.965	3.844	3.789	3.947	4.120	3.933	3.933
47. Salaries of general officers...........	11,676,616	0.842	0.841	0.823	0.925	0.984	0.883	0.883
48. Salaries of clerks and attendants...	18,582,142	1.340	1.313	1.254	1.244	1.262	1.283	1.283
49. General office expenses and supplies.............	3,459,470	0.249	0.230	0.234	0.249	0.257	0.244	0.244
50. Insurance.........	6,885,932	0.496	0.471	0.432	0.412	0.384	0.439	0.439
51. Law expenses.....	7,096,275	0.512	0.513	0.541	0.558	0.549	0.549	0.549
52. Stationery and printing (general expenses)........	2,439,781	0.176	0.170	0.175	0.168	0.161	0.170	0.170
53. Other expenses....	4,861,911	0.350	0.306	0.3330	0.391	0.447	0.365	0.365
Recapitulation of Expenses...........								
54. Maintenance of way and structures	274,415,279	19.784	19.519	21.185	22.255	22.272	21.003	22.354
55. Maintenance of equipment........	288,012,604	20.765	19.967	19.133	19.127	18.629	19.524	12.287
56. Conducting transportation.........	769,613,017	55.486	56.670	55.893	54.671	54.979	55.540	43.454
57. General expenses..	55,002,127	3.965	3.844	3.789	3.947	4.120	3.933	3.933
Grand Total......	1,387,043,0	27100.	100.	100.	100.	100.	100.	82.028

electric operation they should be reduced about one-fourth; in other words, they should approximate 5% of the total operating expenses. It is not to be imagined, of course, that railroads adopting electric traction would limit themselves to equal draw-bar pull and not increase loads. They would, naturally, take advantage of the possibility of increasing draw-bar pull so far as strength of draft-gear may permit, thereby effecting gains far outweighing the decrease in operating expenses represented by saving in maintenance of roadway, rails, and ties, which would result from a decrease in the weight of locomotives. This argument is valid, not only with reference to high-speed passenger traffic, in which the hammer-blow of the engine is emphasized, but also in connection with freight traffic, where in recent years there is a marked tendency to employ trains of great length and locomotives of extreme weight.

The cost of track-maintenance is increased by reason of the electric bonding of the rails. This bonding, including the cost of special bonds necessary where an automatic track signal system is used, will cost about $500 per mile under average conditions. Its cost of inspection and maintenance should not exceed $50 per mile of single track per annum.

The annual cost of " Renewals of rails," " Renewals of ties," and " Repairs and Renewals of bridges and culverts," averages in the United States $400 per mile of track, which as above stated, is 6.633% of average operating expenses, under steam operation, and for equal trains, as we have estimated, 5% for electric operation. The effect of the cost of track-bonding, therefore, would increase the items under consideration by about one-eighth, which is equivalent to an increase of 0.8% in operating expenses. To avoid possible confusion, we include the cost of " Repairs and renewals of track bonding " as a separate item in the column " Estimated Cost of Operation by Electricity."

Under the general conditions which will govern where electricity is substituted for steam in railway operation, there can be no doubt that the substitution will result in a material reduction in the cost of maintenance of rails, ties, bridges, and culverts. In this substitution electric locomotives will be used for freight traffic, while for passenger traffic locomotives will be eliminated ultimately and multiple-unit car equipments employed. For the immediate future, however, locomotives will be employed not only for freight traffic but also in some cases for passenger traffic, for the practical reasons which have impelled the Pennsylvania, the New York Central, and the New York, New Haven & Hartford systems in electrifying their New York terminals to adopt electric locomotives for handling their through trains.

The hammer-blow upon rails, is largely and in some cases wholly avoided by the adoption of electricity; *e.g.*, the entire electric equipment of the heavy locomotives used in the Baltimore tunnel is spring-borne; this is true also of the 70-ton Ganz locomotives recently placed in operation upon the Valtellina, and of the single-phase locomotives ordered by the New York, New Haven & Hartford Railroad. In the case of the locomotives recently constructed for the New York Central Railroad the motor armature is carried by the axle. The armature and axle weigh 7460 lb.; obviously the hammer-blow, even in this case, is not to be compared with the tremendous blow due to unbalanced reciprocating parts, the inertia of which in steam locomotives at high speeds is sufficient actually to lift the wheels from the track.

The hammer-blow is less serious at the speeds at which freight trains usually travel; but even if we ignore entirely the effect of the unbalanced parts in this case, the electric locomotive still possesses the important advantage that its ratio of tractive effort to weight is much higher than that of the steam locomotive.

The most striking feature in American railway operation in recent years is the increase in length of train and weight of locomotive, under pressure of business which has increased at a ratio much exceeding the ratio of increase in track mileage. Despite the efforts of our railway engineers and managers, the roadbed has not kept pace with this advance; and while the weight of rail has been increased materially, the factors of safety as regards weight upon ties and bridges, and particularly as regards the security of rails against displacement due to side-thrust on curves, are by no means what they should be, and yet apparently have reached their limit. Lieut.-Col. Yorke, Chief Inspector for the British Board of Trade, in his report of the results of his observations in the United States in 1903, called particular attention to this fact, and expressed the opinion that American railway practice is tending towards British practice in respect to the distribution of weight on ties secured by inserting chairs between the rails and the ties.

In view of the fact that our railways have been spending large sums of money to increase the stability of the roadbed, to strengthen bridges and culverts, and to maintain rails in position upon the ties, the advantage which the electric locomotive possesses in its higher ratio of tractive effort to weight is important, even in freight traffic at low speed. The necessity of utilizing track capacity to the utmost, and the economies resulting from the operation of long trains, have resulted in gradually increasing the length and weight of freight trains until it would appear that the limit has been reached, unless further improvement draft-gear, track, and roadbed, and further increase in weight of locomotives, be found possible. It is evident, however, that if electric locomotives operated by the multiple-unit system could be used and located at suitable distances throughout the train, the possible length of a freight train would not be limited by its practicable motive power equipment.

Operation of electric locomotives thus located presupposes upon all roads the addition of control-wiring and couplers to freight cars. The report of the Interstate Commerce Commission for 1904 shows that of a grand total of 1,845,304 locomotives and cars operated by our railways, 1,823,030 are equipped with automatic couplers and 1,554,772 are fitted with train brakes. At the present time, the cost of train-line and couplers would approximate $75 a car, but a reasonable cost for the apparatus required, if furnished in large quantities, would not exceed $50 per car.

As regards the making up of trains, it is now necessary to couple the air-line between cars, and the additional labor of connecting the control-couplers would not be serious.

While the cost of equipping freight cars, and of additional labor involved in connecting trains, is very small as compared with the immense advantages which in many cases would result from the ability to distribute locomotives at suitable intervals in a freight train, and control them simultaneously and perfectly by the hand of the engineman at the head of the train, the probability of adoption of multiple-unit operation for freight trains appears remote, since there is apparently no sufficient reason why a railroad company not adopting electricity should equip its cars for electric operation over the lines of another company which may adopt the newer motive power. Whether it be possible for a company desiring to avail itself fully of the advantages of electric traction for freight, as well as for passenger traffic, to bring to bear upon other lines interchanging freight with it, pressure sufficient to induce those lines to spend $50 per freight car for electric equipment is a question outside the scope of our present consideration.

Reverting to Table I, item 5, " Repairs and renewals of fences, road-crossings, signs and cattle-guards," will not be changed by the adoption of electricity.

Item 6, " Repairs and renewals of buildings and fixtures," includes repairs and renewals of engine houses and shops, also water tanks and coal-handling apparatus. Under electric operation, it is evident that this item would be materially reduced. This subject will be further discussed when we come to consider item 12, " Repairs and renewals of locomotives." It is conservative to say that for the operation of a given train-mileage, under the average conditions of railway service in this country, the number of electric locomotives required should not exceed one half the number of steam locomotives now used. The reduction in the number of locomotives implies, of course, a reduction in the cost of repairs and renewals of engine house and shops, and taking this into account, in connection with the elimination of water tanks and coal-handling apparatus, distributed along the line, it is our opinion that this item will be reduced from 2.366% to about 1.3% of the total annual operating expenses.

Item 7, "Repairs and renewals of docks and wharves" obviously will not be affected.

Item 8, "Repairs and renewals of telegraph." It is probable that this item will be somewhat increased in general where electric operation is adopted. The effect upon the operating expenses, however, is so slight as to be practically negligible in our consideration of the general problems of comparative expenses of steam and electric service.

Item 9, "Stationery and printing" will not be changed.

Item 10, "Other expenses" we may assume will not be affected.

Under the general heading "Maintenance of Way and Structures," the classified statement of operating expenses of a railroad electrically equipped includes the following items in addition to the foregoing:

a. "Repairs and renewals of track bonding."

This has been referred to in our discussion of items 2, 3, and 4, and it is included in our tabulated statement as a separate item amounting to 0.8% of operating expenses.

b. "Repairs and renewals of overhead or third-rail construction."

From detailed calculations of the cost of high class overhead construction, where two tracks are to be equipped the cost of overhead construction is approximately $10,300 per mile. This includes trolley conductors equivalent to No. 4/0 wire B. & S. gauge, insulated for 11,000 volts alternating, and supported by steel cables, carried by substantial steel bridges set in concrete, and spanning the tracks. For single-track work using steel poles and brackets and catenery support, the cost closely approximates $4800 a mile.

Of the total line mileage of the United States in 1905, amounting to 216,974 miles, approximately 0.4 are in double track, including yards and sidings for single-track lines, and 0.6 are single-track.

The grand average cost of overhead steel construction of the type considered, therefore, closely approximates $5000 per mile of track. In this case, our estimate of the annual cost of " Repairs and renewals of overhead construction " cannot rest directly upon actual experience, since practically no overhead construction of this character is in use under the conditions of railway service. We may, however, base conclusions which should be reasonably correct upon consideration of first-class overhead trolley construction such as is used by our best interurban lines. Some light is also thrown upon the subject by extensive experience in the operation of high potential transmission circuits, and the experience of the Valtellina line is particularly instructive.

Light steel bridges, set in concrete, subject to the comparatively slight strains involved in supporting the light conductors required, should last almost indefinitely if kept properly painted. The absence of smoke and gasses from locomotives favors their long life. The cost of these steel bridges and poles is a large part of the overhead construction.

The wear of the trolley wire will depend upon density of traffic, but its original cost is only $700 a mile, and judging from the experience of ordinary trolley lines and the results obtained on the Valtellina its life should be long.

The steel catenary cables supporting the conductor being well galvanized should last many years without renewals.

Breakage of insulators, such as are now available, will not constitute a large item of expense.

As regards life of steel structures, it is instructive to note the fact that much of the structure of the Manhattan Elevated lines still in use is more than 30 years of age, and is apparently unimpaired notwithstanding the heavy and frequent traffic which it has carried and still carries.

It is probable that engineering opinion in regard to the amount which should be allowed for " Repairs and renewals of overhead construction " under consideration will not be unanimous, but taking into account all of the factors which appear to affect the problem, it is our judgment that the amount required should not exceed $150 per mile of track per annum. This is equivalent to $210 per mile of line per annum, the average ratio of track-mileage to line-mileage being 1.4 to 1.

The increase in operating expenses due to this item is about 3.25% the average operating expenses per line-mile in the United States for the year 1905 being $6451.00.

It is of course, possible to erect a much cheaper form of construction if wood poles be used. Though the first cost of such construction is low, it involves repairs and renewals constituting a much larger percentage of its cost than in the case of the steel bridge and pole construction set in concrete. The annual effect upon operating expenses with this type of construction as an average figure may be expected to approximate 2.5%.

" MAINTENANCE OF EQUIPMENT.."

Item 11. "Cost of superintendence " will not be changed.

Item 12. " Repairs and renewals of locomotives " amounts to 7.509% of the average operating expenses of our steam railroads. This item, as we find in the classification of operating expenses prescribed by the interstate Commerce Commission, " does not include the expense of cleaning boiler tubes and packing cylinders, nor ordinary regular inspection, this being charged to the item " Engine and Roundhouse Men." It does include " all expenditures for account of repairs and renewals and rebuilding of locomotives, tenders, snow-plows (when attached to locomotives), furniture and loose and movable tools and supplies used in connection therewith. It also includes the cost of locomotives, tenders and appurtenances thereunto belonging, built or purchased to make good the original number charged to construction or equipment."

As regards " Repairs and renewals of electric locomotives," actual experience to date is not sufficient to justify us in fixing a figure for this item which can be regarded as established. There is, however, evidence sufficient to justify an estimate which in the average case should be approximately correct.

Before considering data based upon experience, it is pertinent to remark that a moment's consideration of the constituent details of mechanism, their relative complexity, and their respective functions, leads directly to the conclusion that the repairs and renewals of an electric locomotive should be very small as compared with the same item of expense in the operation of a steam locomotive. If we imagine for a moment that electric locomotives had been in use for many years while steam locomotives had but recently come forward as competitors, and that the engineering world of to-day being familiar for years with the essential simplicity of the electric motor as applied to traction purposes, were now called upon to judge the comparative merits of the essentially complicated aggregation of mechanism which we call a steam locomotive, the verdict, as regards the relative cost of repairs and renewals to be expected, is obvious but the argument *a priori* cannot be conceded, and we proceed to consider such evidence based upon comparative results in actual service as we have been able to secure.

1. INTERBOROUGH RAPID TRANSIT CO., MANHATTAN DIVISION.

In the operation of the Manhattan Railway under steam and electric traction, respectively, data for interesting comparisons are afforded; although owing to the fact that in this case multiple-unit electric equipment, applied to two-thirds of the cars constituting the trains, has been substituted for the steam locomotive, the comparison is less favorable to electric operation so far as this item of expense is concerned than it would be were electric locomotives used. The reason is found in the relatively great complication of multiple-unit equipment as compared with locomotive equipment; as a result of this the number of parts in this case is multiplied in the approximate proportion of three to one, and the cost of repairs and renewals is therefore radically increased beyond what it would be were electric locomotives employed.

For the year ending June 30, 1901, the car-mileage operated by the Manhattan Railway was 43,860,158. The cost of repairs of locomotives was $173,609, or 0.39 cents per car-mile.

For the year ending June 30, 1906, the car-mileage operated by the Manhattan Railway was 61,723,112. The cost of repairs of the electric equipment, including lamps, lamp wiring, and heaters, was $171,927, or 0.28 cents per car-mile.

Had electric locomotives been used instead of the multiple-unit system, the number of parts constituting the electric equipment, as stated, would have been about one-third that now in use. These parts would have been larger and more expensive than the corresponding individual parts constituting the multiple-unit equipment, but the cost of repairs of the aggregate electrical equipment (which is largely labor of inspection) probably would not exceed 60% of the present cost. The results are further influenced unfavorably to electric traction as regards this comparison by the fact that the speed, and consequently the power consumption per car, have been radically increased, and by the fact that the repairs and renewals of lamps, heaters, and wiring are included.

A careful consideration of the detailed factors involved has led us to the conclusion that had electric locomotives been substituted for steam locomotives, and had the weight and speed of trains not been increased, the cost of repairs of electric equipment would have approximated 0.2 cents per locomotive mile. We estimate also that the cost of repairs to these small locomotives exclusive of their electric equipment operating under the existing conditions would not have exceeded 0.2 cents per locomotive-mile, and that the total cost would have approximated one-fourth of the cost of the corresponding item under steam traction. This figure of course is available only as a ratio in our consideration of the general railway problem.

The very low cost which was actually obtained in the case of steam locomotives on the Manhattan; viz., 1.57 cents per locomotive mile, is explained by the extremely simple construction of the engines, the fact that they were not overloaded, were operated on an elevated structure, and were admirably maintained. It is also to be noted that the amount expended for repairs was minimized in view of the contemplated adoption of electricity.*

In applying to the general railroad problem evidence afforded by Manhattan experience, it must be noted that the elevation of the tracks places the motors beyond the reach of the dust or cinders which the rush of a train at certain seasons raises from the average railway track. On the other hand, the fact that the average run between stations on the elevated system is only about 2000 ft. exposes both motor and control to the action of brake-shoe dust which is liberated in quantities many times as great as would be the case in average railway service, and this brake-shoe dust is far more injurious to both motors and control than is dust from disintegrated ballast or cinders.

In designing electric equipment for general railway service, it is advisable and not difficult to protect the motors effectively against the admission of dust of all kinds, particularly in cases where locomotives rather than multiple-unit equipment is adopted. This would be accomplished naturally by thoroughly enclosing the motor, and ventilating it by forced draft so directed as to prevent admission of dust.

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*In this connection it is interesting to note that the cost of maintenance of locomotive and average train under steam operation for the year ending June 30, 1901, was 4.2c. per train-mile while the cost in the case of an equivalent electric train, as shown by records for corresponding months for the year ending June 30, 1906, was 2.1c. per train-mile.

2. INTERBOROUGH RAPID TRANSIT COMPANY, SUBWAY DIVISION

For the year ending June 30, 1906, the car-mileage operated by the New York Subway was 31,931,073. The cost of repairs and renewals of electric equipment of rolling stock was 0.38 cents per car-mile. Estimating the probable cost of repairs and renewals of electric equipment, were electric locomotives in use instead of the multiple-unit car equipment, the approximate cost in this case works out at 0.7 cents per train-mile. A locomotive doing the same work as the electric equipment of the average train in the subway (about five cars) must be capable of exerting a draw-bar pull of 30,000 lb., which with 20% adhesion calls for 75 net tons on drivers. This is about double the weight on drivers of the average steam passenger locomotive, and the figure 0.7 cents per train-mile, obtained in actual service under conditions very severe in respect to maintenance of electric equipment, by reason of the presence of great quantities of brake-shoe dust, is to be compared with the cost of maintenance of steam locomotives exclusive of running-gear, frame, cab, and those other parts common to both electric and steam equipment.

3. WILKES-BARRE & HAZLETON R.R.

Operation for the year 1905:

Equipment comprises motor cars weighing 43 tons without passengers, and equipped with four 125-h.p. motors and multiple-unit control.

Effective draw-bar pull (20% adhesion) = 17,000 lb.

Speed of operation in local service = 30 miles per hour.

Total length of run = 27 miles.

Average number of stops = 6.

Car-mileage operated in 1905 = 262,947.

Cost of repairs and renewals of electric motors = $1,021.70 = 0.39 cents per car-mile.

This road operates in a mountainous country, ranging in elevation from about 500 ft. to 1700 ft. above sea-level. About one-third of the length of the road is on a grade of 3%.

4. LACKAWANNA & WYOMING VALLEY RAILROAD.

Operation for a period of four months ending October 31, 1906:

Equipment: *a*, 16 passenger cars, 77,500 lb. each; *b*, 14 passenger cars, 64,500 lb. each; *c*, 4 freight and express motor cars, 61,300 lb. each; *d*, 1 electric locomotive, 94,600 lb.

Car-mileage operated = 527,554.

Repairs and renewals of electric equipment = $4,450.43 = 0.84 cents per car-mile.

5. NIAGARA, BUFFALO & LOCKPORT RAILROAD.

Operation for a period of six months ending Nov. 30, 1906:

Equipment: passenger cars weighing about 60,000 lb., driven by four direct-current motors.

Average speed outside of Buffalo city limits, 20 miles an hour. Approximate number of stops one way trip: 30 on Buffalo & Niagara Falls division, and 6 on Buffalo & Lockport division.

Length of run outside of Buffalo, approximately 20 miles.

Car-mileage operated, 1,309,682.

Repairs and renewals of electric equipment, 0.79 cents per car-mile.

6. RETE ADRIATICA-VALTELLINA LINE.

Perhaps the best instance of electric operation directly comparable with cost of steam operation is afforded by the records of the actual results realized on the Valtellina line where both freight and passenger traffic are operated over a line 66 miles in length, traversing a very rugged country and in the winter exposed to severe climatic conditions. The equipment for the year ending July 1, 1904, comprised 10 motor cars and five 70-ton locomotives. The service performed amounted to 61,934,569 ton-kilometers. The average annual mileage of motor cars and locomotives amounted to 54,351 kilometers, while the steam locomotives superseded by electric equipment never exceeded an average of 29,000 kilometers.

The total cost of electrical and mechanical repairs to locomotives and motor cars, for the year ending July 1904, works out at 1.4 cents per locomotive or motor car-mile. The rolling stock used on this line is excellent in design and construction and is particularly well adapted to operate in railway service at low cost of maintenance, by reason of the fact that three-phase motors and water rheostats are employed instead of commutating motors and switch-control. The equipment has not been operating long enough to have reached the point where renewals, as distinguished from repairs, have become necessary.

Summarizing the foregoing we have the following:

	Tractive effort 20% adhesion	Repairs of electric equipment of equivalent electric locomotive. Estimated.	
Manhattan Railway	22,000 lb.	0.5¢	
Subway train	33,000 "	0.7¢	
Wilkes-Barre & Hazleton R.R.	17,000 "	0.38¢	(actual)
Lackawanna & Wyoming Valley R.R.	14,000 "	0.84¢	"
Niagara, Buffalo & Lockport R.R.	12,000 "	0.79¢	"
Rete Adriatica-Valtellina line		1.6¢	Complete cost of maintenance of locomotives and cars.
Freight locomotives			
Passenger cars			

It may be conceded freely in respect to the foregoing data that they are neither sufficiently comprehensive in scope nor extended in respect to duration of service to justify definite and final conclusions. It must be noted also on the one hand that the cost of maintenance may be expected to decrease by reason of further improvement in the construction of apparatus of comparatively new types, and on the other hand that the costs given are for inspection and repairs rather than renewals, since the time has not arrived when any of this equipment has been thrown aside and replaced by new equipment charged to this item of operating expenses as is usual with steam railways.

The reports of the Interstate Commerce Commission do not show what proportion of the item, " Repairs and renewals of locomotives " is chargeable to renewals, but from inspection of detailed reports of our most important railway systems it seems fair to assume that in the case of the average railway from 4% to 5% of the total cost of repairs and renewals of locomotives represents the cost of renewals.

Taking into account all of the various considerations which must affect the conclusions in the general case, so far as we have been able to gather them, we are of the opinion that for equal draw-bar pull, the repairs and renewals of electric equipment of locomotives, assuming good design and construction according to present standards of the art, should not exceed 1 cent per locomotive-mile, and will probably approximate 0.9 cent per locomotive-mile.

Taking the higher figure, it is evident that the substitution of electric equipment for all parts of a steam locomotive other than frame, wheels, axles, cab, and other parts which are common both to electric and steam locomotive construction, a very great saving is effected. We have been unable to fix with satisfactory exactness a figure representing the average cost of repairs and renewals of these parts, but it would seem liberal to allow 1.5 cents per locomotive-mile, this being equivalent to an allowance of something over $400 per annum per locomotive. Taking this figure and adding the estimated costs of repairs and renewals of electric equipment, we have 2.5 cents per locomotive-mile as the estimated total cost of repairs and renewals of electric locomotives, performing the average work now done by steam locomotives.

In 1904 the aggregate revenue train-mileage operated was about 1,050,000,000. To cover locomotive mileage in switching, operating work-trains, and pushers we assume 1,300,000 locomotive-miles. In 1904 the aggregate repairs and renewals of locomotives was $105,633,752, the average cost per locomotive-mile, therefore, being 8.1 cents. A reduction of 2.5 cents, therefore, is equivalent to a saving of 70% in the cost of this item, or 5.256% of operating expenses, reducing this item to 2.253% of total operating expenses under electric operation.

In the foregoing consideration of the item repairs and renewals of locomotives, we have assumed equal locomotive mileage per day in steam and electric service. The item of expense under consideration will be proportional approximately to the mileage, and therefore we have made the comparison upon this basis.

The relative number of locomotives required for a given service is, however, a question of much importance and may be here appropriately referred to.

According to the report of the Interstate Commerce Commission for 1904, the aggregate train-mileage operated in the United States as above stated was 1,050,000,000. The locomotives in service numbered 46,743. The effective train-mileage, not including work-trains, pushers, or shifting mileage, was 58 miles per locomotive per day. We have been unable to ascertain from the report of the Commission what percentage should be added to this figure to cover accurately the locomotive mileage of work-trains and shifting and to take account of double headers and pushers, but inspection of the report of a number of our leading railways indicates that the effective train mileage averages from 70% to 75% of the locomotive mileage. It follows, therefore, that the daily run of the average locomotive in the United States is approximately 80 miles. Naturally there is a wide variation in the performance of locomotives on various lines; *e.g.*, passenger mileage as shown by reports of some of our leading railways varies from 90 miles to nearly 200 miles a day and individual cases are reported of locomotives making as much as 300 miles a day.

The average freight locomotive is actually on the road not more than 6 hours in each 24-hour period, and the same figure is approximately correct for the average passenger locomotive. In the case of electric locomotives there is no reason, so far as the mechanism is concerned, why it cannot be kept in practically continuous service. Ordinary inspection and maintenance require very little time, and if the equipment be well designed and constructed repairs of magnitude will be necessary only at intervals very infrequent as compared with steam practice.

The fact that the average daily run of the average locomotive is approximately 80 miles, is due in large measure to causes which would still exist were electric locomotives substituted. The time spent by freight locomotives in yards and terminals making up trains or awaiting opportunity to take their place in the processions of trains which in these days are demonstrating the insufficiency of track equipment for the business of the country, is a large factor. Perhaps this would not be greatly modified were electric locomotives employed. But other considerations which operate to reduce average mileage are the facts that the steam locomotive spends a large part of its life in the repair shop, and a still larger part in firing up and preparing for its work and in withdrawing fires, having boiler tubes cleaned, etc., after its daily run. Nothing short of years of actual experience can establish definitely the ratio of electric to steam locomotives required in average service, but it seems reasonable to assume that this ratio will not exceed 2 to 3 and will probably approximate 1 to 2. It will be noted that the foregoing estimate of cost of repairs and renewals is independent of any assumption as to the relative number of locomotives required since it is reckoned on locomotive mileage.

Item 13. "Repairs and renewals of passenger cars." In cases where electric locomotives are substituted for steam locomotives, there should be some reduction in this item. Painting should be considerably reduced by reason of the elimination of smoke. The life of the upholstery and interior decoration of the car will be increased.

Item 14. " Repairs and renewals of freight cars." This item will be favorably and very materially affected if it should ever prove practicable to operate heavy freight trains by locomotives located at intervals throughout the trains and controlled by the multiple-unit system. As has been pointed out, however, this will become practicable only when a large proportion of the freight cars in use are supplied with electric train line equipment. The bare possibility of this at present may seem fanciful, but those who realize the extent to which the wear and tear of freight cars results from the terrific strains to which the draft-gear is subjected under present operating conditions, especially on mountain grades, and who understand also the increase in track capacity and decrease in cost of train crews which would result in the adoption of a system which makes it possible, if necessary, to double the length and weight of the longest and heaviest freight trains now in use, will be ready to give this possibility serious consideration. The mere substitution of electricity for steam without altering the present make-up of trains, so far as location of the locomotive is concerned, makes it possible to operate two or more locomotive units at the head of the train, and to utilize their power to the utmost by multiple-unit control operated by a single operator on the leading engine.

Assuming that the methods of train operation remain the same, the adoption of electricity will still effect a reduction in the cost of Item 14, and for two reasons, viz;

1. The practical elimination of damage by fire which now frequently is superimposed upon damage caused by collision or derailment.

2. Reducting the wear and tear of wheels and brake equipment in descending long grades, by reason of the opportunity afforded to break the trains by causing the motors to operate as generators. On lines where grades are heavy and of considerable length, the saving thus effected will be large. Generally speaking, the energy developed by the motors working as generators will be returned to the overhead circuit and utilized in coöperation with energy from the power house to furnish power to trains on the same division which may be ascending the grade.

No statistical data are available upon which to base an estimate of the probable reduction in this item to be expected from this cause. On comparatively level lines it will not be importınt, but on mountain-grade divisions it should operate to prevent a very large proportion not only of wear and tear directly due to grade but also of the destructive freight wrecks which are now so frequent. In the way of an estimate, nothing more definite than a guess based upon consideration of probabilities, and the views of various operating officials, can be advanced; but in the opinion of the writers the general substitution of electricity for steam operation in freight service should reduce this item from 7.657% to something like 6% of operating expenses.

Item 15. " Repairs and renewals of work cars," will not be changed materially.

Item 16. " Repairs and renewals of marine equipment," obviously will not be changed.

Item 17. " Repairs and renewals of shop machinery and tools," will be reduced under electric operation since the repairs to locomotives will be radically decreased as shown and since the tool equipment required for the electrical machinery is materially less expensive and varied.

It would seem reasonable to expect that this item would be reduced from 0.662% to about 0.5% of total operating expenses. Of course a large proportion of the shop machinery and tools are for car repairs.

Item 18. " Stationery and printing," will not be changed.

Item 19. " Other expenses." The classification of operating expenses includes under this item " all expenditures for account of electric light, torches and lamps used in machinery department, shops, roundhouses and offices and the oil and material for the same; the proportion of labor and material for the proper operation and repair of electric lights used in connection with other departments; wages of engineers and firemen and the cost of fuel and water in operation of stationary engines or boilers for supplying power and heat to shops, buildings and roundhouses."

Other factors comprised are comparatively small and it is evident that the ability to use electricity for light and power purposes in shops, roundhouses and offices produced at a works cost of 0.6 cents and delivered to the point of consumption at a figure which on the average will approximate 0.75 cents will effect a material reduction in this item. We estimate that it will be reduced to about 0.4 cents.

CONDUCTING TRANSPORTATION.

Item 20. " Superintendence," will not be changed.

Item 21. " Engine and roundhouse men," includes in addition to the engine crew, round-house men whose work, of course, is chiefly in connection with the cleaning and maintenance of the engines. This item averages for the railroads of the United States 9.451% of the operating expenses, of which 91%, or about 8.6% of the operating expenses are for engine men and for firemen. Of this 8.6% approximately 5.5% is for engine men and 3.1% for firemen.

In considering the substitution of the electric locomotive for the steam locomotive it is obvious that the change eliminates the work which the fireman is employed to perform. The point is frequently made, however, that to reduce the engine crew to one man means an increase in the risk incurred in train operation and this point obviously is of such importance as to require careful consideration.

If we compare conditions which now exist upon such systems as the Manhattan Elevated with the conditions which existed before electricity was adopted, it seems reasonably clear that with a competent motorman operating a controller which instantly cuts off power and applies the brakes in case the hand of the motorman is removed from the handle of the controller, the safety of trains and passengers is assured in higher degree than it was under the old conditions. The usual argument against the elimination of the fireman is of course, found in the allegation that in case of the sudden death or serious illness of the engineman the fireman can take his place and bring the train to a stop or operate it to the next station. The controller which automatically cuts off power and applies the brakes cannot operate the train to the next station, but it can stop it much more promptly than the fireman possibly can, even when he is so located upon the engine as to be in sight of the engineman.

But a very large proportion of our steam locomotives are now designed in such a way that the engineman is not in sight of the fireman, and the mechanism of the steam locomotive which he controls has no automatic device for shutting off power and applying the brakes in case he suddenly dies at his post. In such an emergency on trunk-line railways there would be some advantage in the presence of the fireman, owing to the fact that if competent he could operate the train to the next station. This point might be met by having the train conductor or brakeman or flagman qualified to operate the electric train to its destination in case of accident to the motorman. The degree of skill required, so far as actual manipulation of the mechanism is concerned, would be far less than in the case of the fireman who might in emergency be entrusted with the responsibility of operating the steam train.

It would seem, therefore, that there can be no question of the reasonableness and safety of entrusting the operation of an electric locomotive to one man, provided the control system is equipped with effective appliances arranged to cut off the power and apply the brakes in case the motorman's hand leaves the hand of the controller.

As regards the wages of the engineman, the Manhattan Railway decided to pay its motormen the same wages which it had paid its enginemen. This decision was based largely upon consideration of the fact that familiarity with the road and experience in operating trains under the extremely close headway prevailing upon this system were of such importance that any risk which might be incurred by substituting new men must be avoided. The great majority of electrically equipped railways operating under conditions similar to the Manhattan, however, pay their motormen wages comparable to the wages of the men who operate street cars rather than to the wages of locomotive enginemen.

The work required of the motorman operating an electric train is far less onerous and is performed under conditions much less severe than is the case with the locomotive engine-driver, nor is the motorman in order effectively to perform his duties required to serve years of apprenticeship during which he must become familiar with the complicated mechanism under his control and competent to make upon the road any ordinary emergency repairs. The work required being relatively easy, the apprenticeship comparatively short, and the mechanical knowledge necessary greatly reduced, it is reasonable and proper that the compensation of the motorman, under average conditions, should be less than that of the engineman.

Apart from the attitude to be expected upon the part of employees, and aside from any question of sentiment, however, the management of a railway contemplating the substitution of electricity for steam would not be justified in lowering the standard so far as character and judgment are concerned, which are requisite for the motorman equally with the engineman. It must be remembered also that familiarity with the road and with signals, etc., are as important in his case as in that of his predecessor.

It is impossible of course to fix with definiteness a figure representing the wages of the motorman in railway service as compared with that of the engineman whom he may succeed, but it seems reasonable to assume that under average conditions the services of thoroughly competent motormen can be obtained at a figure which will represent a reduction of 1% in operating expenses, making this item 4.5% instead of 5.5%.

The expense for round-housemen, which under steam operation is about 8.5%, will be greatly reduced both by reason of the reduction in the number of locomotives required for a given service and also by reason of the demonstrated less cost of maintenance per locomotive unit. It is entirely liberal to allow for this item one fourth of its cost in steam operation, the saving here effected being equal to 0.64% of the average operating expenses of steam railroads in the United States.

The estimated cost of the item under consideration, therefore, is 4.71% of total operating expenses.

Item 22, " Fuel for locomotives." One of the marked economies resulting from the substitution of the electric motor for the steam locomotive in railway operation is in the reduction of the fuel account. The cost of fuel upon the average steam railway in the United States for the five years 1901 to 1905 inclusive constituted 11.292% of total operating expenses. The aggregate cost in 1905 was $156,429,245.

The following figures show comparative fuel consumption upon the Manhattan Railway during the year ending June 30, 1901, when steam locomotives were employed and during the year ending June 30, 1904, when electricity was used. During the period first mentioned one pound of coal produced 2.23 ton-miles, if the weight of the locomotive be included, and 1.5 ton-miles, if the weight of the cars only be considered.

During the latter period (electric traction) one pound of coal burned at the power house produced 3.85 ton-miles, excluding weight of locomotives; therefore, the ratio of ton-mileage per pound of coal in favor of electric operation was 2.57 to 1. Including weight of locomotive it was 1.72 to 1.

The average speed under electric operation was approximately 2 miles an hour greater than that attained by steam, and if correction be made for this difference the ratio of ton-mileage per pound of coal excluding weight of locomotives is approximately 3 to 1, and including locomotives 2 to 1 in favor of electric traction. It should be noted also that in this case the coal burned at the power house was of lower grade, and therefore less expensive than that used by the locomotives, and it is reasonable to expect that in general electric traction will mean utilization of cheaper fuel.

We would point out that the argument from Manhattan experience cannot be met by the statement that the Manhattan is not an average railroad. Were the steam and electric apparatus now operating the Manhattan lines applied to the operation of a division of a trunk-line railway, the one part of the system which would be affected in respect to efficiency is the high potential transmission lines, and the effect of their greater length in general would be to increase the relative fuel consumption of the electric system by not more than 5%. For trains drawn by locomotives the fuel account (coal only) under electric operation would still be approximately one-half of the cost of the fuel for steam operation, and for passenger service using multiple-unit equipment it would be less than 40% of the fuel used in equivalent steam service, even if we assume that the system of alternating transmission and conversion to direct current by synchronous converters be employed.

The advantage in favor of electric operation is of course more marked if we assume that alternating-current equipment is to be used, as in general would be the case in the electrification of trunk lines or long divisions. In a particular case which we have worked out with great care, the trolley and track rail losses average 3.9%, the load factor being 0.33. This is the result obtained in using the single-phase system for the equipment of a division approximately 40 miles in length, the potential being 11,000 volts. The grand average of traffic in the United States does not exceed seven trains per day passing a given point in each direction, and the trolley and track rail energy losses for this traffic would be less than 2%.

Assuming that such a trolley voltage is used in connection with a feeder potential of say 40,000 to 60,000 volts, the allowable loss in these feeders at maximum load certainly will not exceed 10% and the energy efficiency of step-up transformers, transmission feeders, and step-down transformers will be 92%. Combining this figure with the energy efficiency of trolley and track, as above stated, the resultant efficiency from bus-bars of power house to the train will be 90%.

The works-cost of a kilowatt-hour at the bus-bars of the Manhattan plant is less than 0.6 cent when coal costs $3.00 per ton, this coal having a calorific value of 14,000 B.t.u. per lb. This cost includes fuel, water, labor, maintenance, miscellaneous supplies, and in short everything except capital charges. It is not abnormally low, the cost of both coal and labor being relatively high as compared with the grand average cost of equivalent coal and labor throughout the United States. Where fuel is less expensive, as in the middle West, large modern plants, using steam turbines, are producing the average kilowatt-hour at a price not exceeding 0.5 cent exclusive of capital charges, and in at least one case at a works-cost approximating 0.4 cent.

As will be shown hereinafter, were all the railroads of the United States to be operated by electricity, the average plant required, assuming power to be transmitted 150 miles, would approximate 4,000 kw. if the plants supplied but a single line 300 miles in length. The great bulk of the total power supplied, however, would be derived from large plants in which the cost of producing the unit of energy, considering average costs of fuel and labor, should be less than 0.6 cent. While the small plants would exceed this figure we believe that as a grand average 0.6 cent is ample to cover the case. In this connection, it may be remarked that water powers and other sources of cheap power supply would tend to keep down the average cost of power under the assumed condition of electrification of the entire railroad system of the country.

In the case of the single-phase, 25-cycle motor, assuming the average length of run for freight trains to be 15 miles and for passenger trains 20 miles, we have calculated that of the energy delivered to the locomotive approximately 86% will be effective fort raction in the case of the passenger locomotive, which is gearless, and about 84% in the case of the freight locomotive, which uses single-reduction gear. Combining the two, it is safe to say that of the energy supplied at the bus-bars in the power house not less than 75% will be effective for traction in the average locomotive equipped with this apparatus.*

The cost of a kilowatt-hour effective for traction therefore is 0.8 cent and the cost of a horse-power hour effective for traction about 0.6 cent of which 0.35 cent is for fuel when coal of 14,000 B.t.u. per lb., costs $3.00 per ton of 2240 lb., and 0.25 cent is for other power-house supplies, power-house labor, and maintenance of power-house equipment.

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*For the motor curves upon which these figures are based, we are indebted to the courtesy of the Westinghouse Electric & Mfg. Co.

As we have stated, the railroads of the United States in 1905 used coal costing $156,429,245. For the purpose of estimating the cost of equivalent electric power the following data are necessary, of which those marked by an * are furnished by the report of the Interstate Commerce Commission while the others involve certain assumptions:

PASSENGER SERVICE

*Passenger train-miles.
Passenger car-miles.
*Passenger-miles.
Average weight of passenger trains:
  a. Weight of locomotives.
  b. Weight of cars.
  c. Weight per passenger.
Average speed of passenger trains.
Average length of run.
*Mail and express train-mileage.
Average weight of mail and express trains.
Non-revenue ton-mileage.

FREIGHT SERVICE

*Freight train-mileage.
*Freight car-mileage.
*Revenue freight ton-miles.
Average weight of freight trains:
  a. Weight of locomotive.
  b. Weight of cars.
Average speed of freight trains.
Average length of run.
Non-revenue ton-mileage, work-trains, switching, etc.

Referring to the several items in the foregoing lists not directly derived from the report of the Interstate Commerce Commission the assumptions made are as follows:

PASSENGER SERVICE

Passenger Car-Miles: These we have calculated from the stated train mileage and the assumption that the average number of cars per train is 5.5.

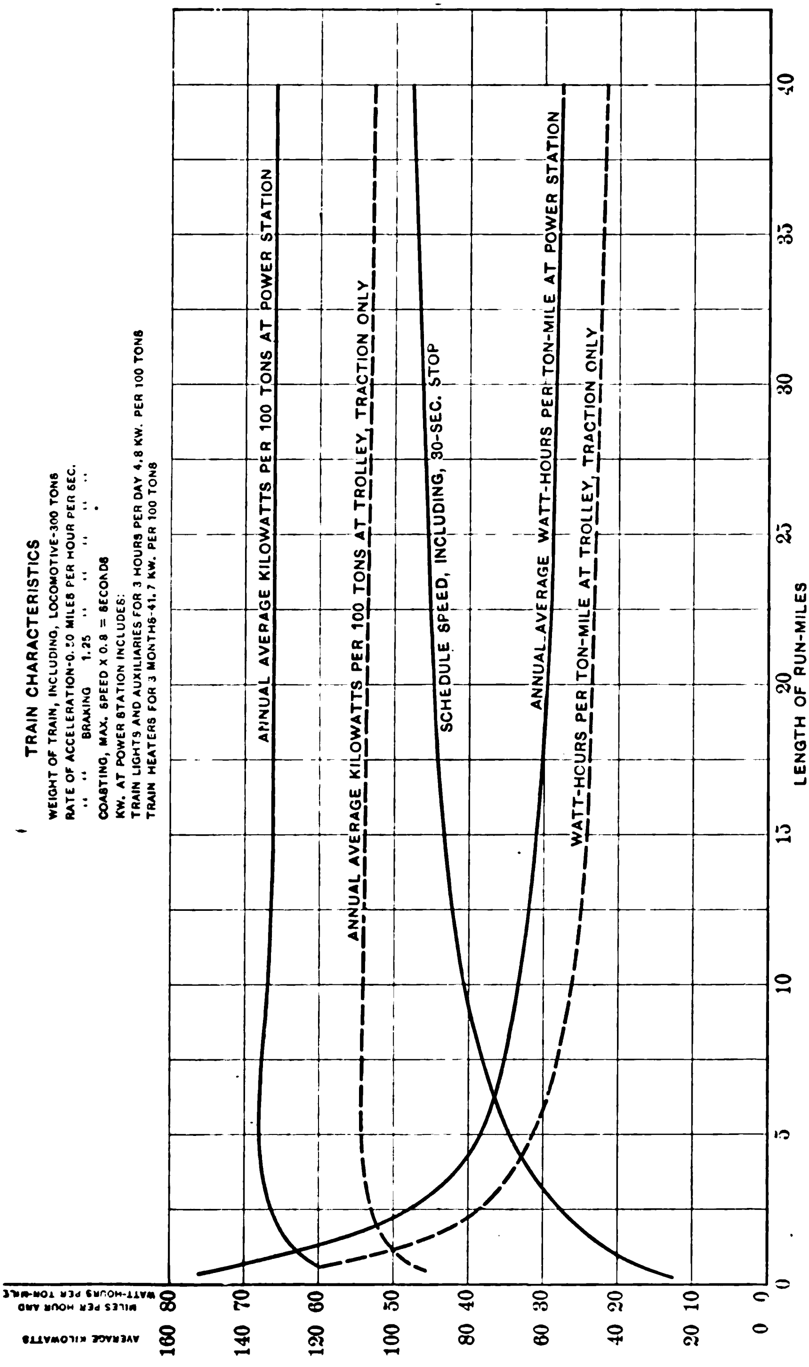
TRAIN CHARACTERISTICS
WEIGHT OF TRAIN, INCLUDING, LOCOMOTIVE-300 TONS
RATE OF ACCELERATION-0.50 MILES PER HOUR PER SEC.
" " BRAKING 1.25 " " " " "
COASTING, MAX. SPEED X 0.8 = SECONDS
KW. AT POWER STATION INCLUDES:
TRAIN LIGHTS AND AUXILIARIES FOR 3 HOURS PER DAY 4.8 KW. PER 100 TONS
TRAIN HEATERS FOR 3 MONTHS-41.7 KW. PER 100 TONS
ANNUAL AVERAGE KILOWATTS PER 100 TONS AT POWER STATION
ANNUAL AVERAGE KILOWATTS PER 100 TONS AT TROLLEY, TRACTION ONLY
SCHEDULE SPEED, INCLUDING, 30-SEC. STOP
ANNUAL AVERAGE WATT-HOURS PER TON-MILE AT POWER STATION
WATT-HOURS PER TON-MILE AT TROLLEY, TRACTION ONLY
AVERAGE KILOWATTS
MILES PER HOUR AND WATT-HOURS PER TON-MILE
160 80
140 70
120 60
100 50
80 40
60 30
40 20
20 10
0 0
0
5
10
15
20
25
30
35
40
LENGTH OF RUN-MILES

FIG. 5.

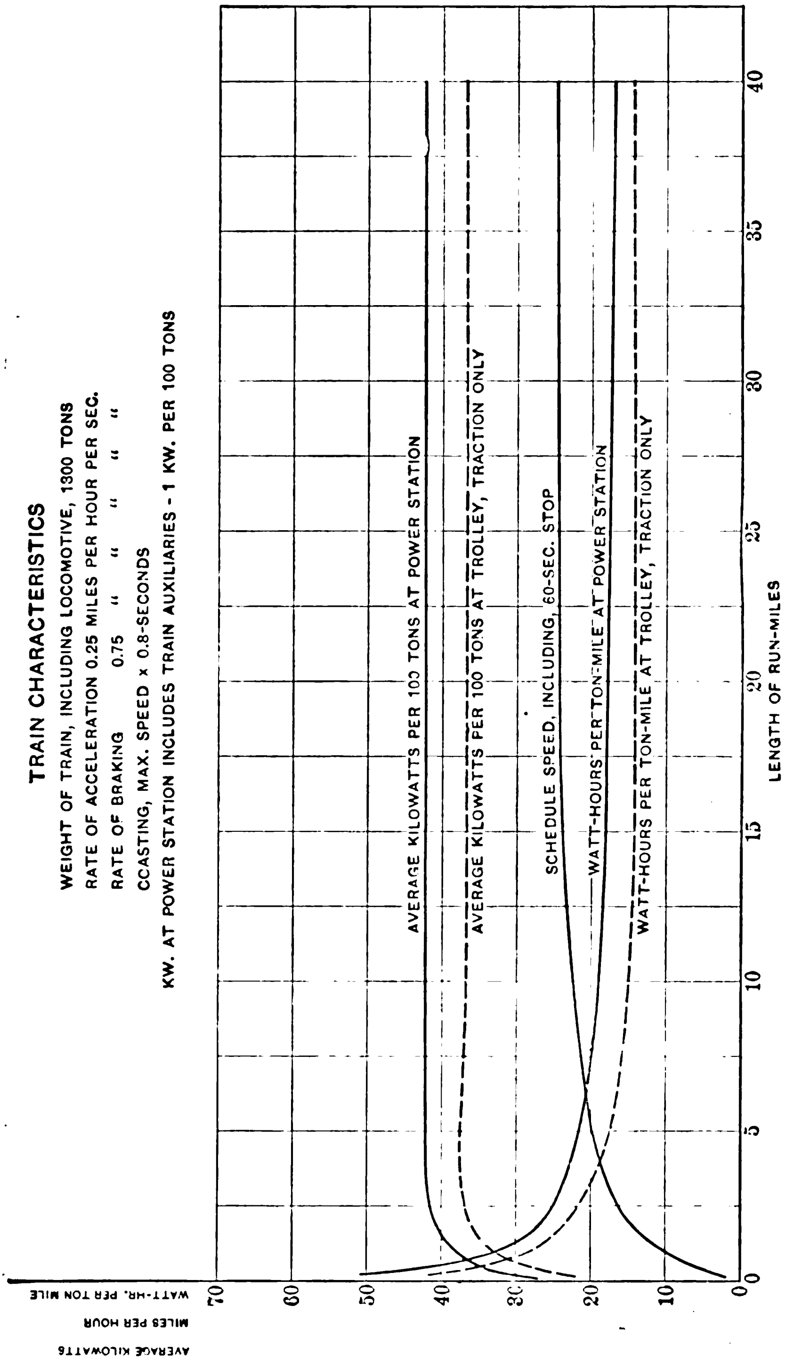
TRAIN CHARACTERISTICS
WEIGHT OF TRAIN, INCLUDING LOCOMOTIVE, 1300 TONS
RATE OF ACCELERATION 0.25 MILES PER HOUR PER SEC.
RATE OF BRAKING 0.75 " " " " "
COASTING, MAX. SPEED x 0.8-SECONDS
KW. AT POWER STATION INCLUDES TRAIN AUXILIARIES - 1 KW. PER 100 TONS
AVERAGE KILOWATTS PER 100 TONS AT POWER STATION
AVERAGE KILOWATTS PER 100 TONS AT TROLLEY, TRACTION ONLY
SCHEDULE SPEED, INCLUDING, 60-SEC. STOP
WATT-HOURS PER TON-MILE AT POWER STATION
WATT-HOURS PER TON-MILE AT TROLLEY, TRACTION ONLY
WATT-HR. PER TON MILE
MILES PER HOUR
AVERAGE KILOWATTS
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
LENGTH OF RUN-MILES

Fig. 6.

Average Weight of Passenger Trains: We assume,

a, Weight of the average locomotive exclusive of tender equals 60 tons; this is the weight of the average passenger locomotive used by the Erie system;

b, Average weight of ordinary passenger coaches without live load equals 30 tons. This weight is somewhat in excess of the average weight of cars used by a number of railroads using rolling stock undoubtedly representative of the average in use throughout the country. To this we have added 10% in estimating train weight to cover additional weight of Pullman cars.

c, Average number of cars in trains. We assume five and a half cars per train which is approximately correct for a number of the more important railroads and is probably slightly above rather than below the grand average.

d, Weight per passenger. We have assumed an average weight of 140 lb.

Average Speed of Passenger Trains: Referring to Fig. 5, the curve expressing the variation in the amount of energy required for traction as dependent upon average length of run between stations, shows that the increase resulting from a decrease in length of run from 20 miles to 10 miles is but 10%. If the average length of run be further decreased to 5 miles, the increase of energy for traction as compared with that required for a 10-mile run is approximately 18%.

Including energy required for heating and lighting the cars, it is not far from accurate to assume 33 watt-hours output at power-house per ton-mile in average passenger service.

Average Length of Run: We have assumed, as stated, 33 watt-hours at power house per ton-mile including light and heat. This corresponds to an average run of 10 miles.

Average Weight of Mail and Express Trains: We have assumed average weight of mail and express trains to be the same as that of the average passenger train, viz., 180 tons without locomotive or live load.

Non-Revenue Ton-Mileage: This is assumed at 10% to cover "double-headers" and switching. For the entire Erie system the actual figures approximate 7%, and the assumption of 10% is slightly less favorable to electric traction than the facts would probably warrant.

Freight Service.

Average Weight of Freight Trains: As regards freight service, in estimating the average weight of trains we have assumed the following:

a, Weight of locomotives equals 79 tons. This is the actual average of the freight locomotives of the Erie system exclusive of tender.

b, Weight of cars equals 15 tons. This figure closely approximates the average weight of all freight cars belonging to the Erie Railroad Company.

Average Speed of Freight Trains: Our curves (Fig. 6) are based upon a gear ratio which produces on straight and level track a maximum speed of 25 miles an hour.

Determination of the error involved by any mistake in our assumption of the average speed in freight service is facilitated, which shows. for example, the following relations:

Maximum Speed	Average speed including 60 seconds stop miles per hour	Average watt-hours per ton-mile at power station
20	19	17
25	23	18
30	27	19

Average Length of Run: We have assumed that for all freight service the average length of run is 15 miles. The actual average length of run may vary considerably from the distance assumed without causing material error in our calculation as shown in Fig. 6.

Non-Revenue Ton-Mileage: We have added 15% to the total revenue earning ton-mileage.

Basing our calculations upon the foregoing statistical facts and the assumptions noted, we estimate that for the operation of the entire freight and passenger service of the United States as existing in 1905, the aggregate energy required at bus-bars of power houses would approximate 12,500,000,000 kilowatt-hours per annum.

At 0.6 cent per kilowatt-hour the total cost of energy for traction, for the operation of all auxiliaries, and for the supply of light and heat to passenger trains would closely approximate $76,000,000 per annum. This figure represents a saving of about $80,000,000 as compared with the coal used by steam locomotives in the year 1905.

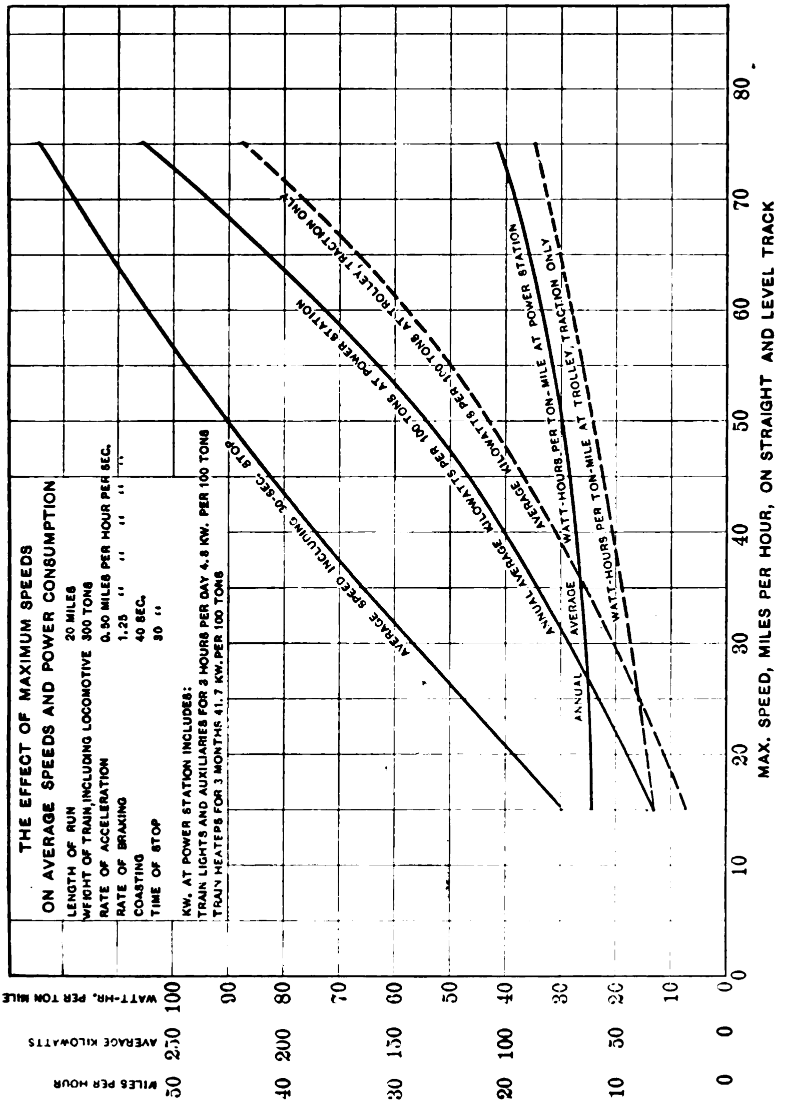
THE EFFECT OF MAXIMUM SPEEDS
ON AVERAGE SPEEDS AND POWER CONSUMPTION
LENGTH OF RUN 20 MILES
WEIGHT OF TRAIN, INCLUDING LOCOMOTIVE 300 TONS
RATE OF ACCELERATION 0.90 MILES PER HOUR PER SEC.
RATE OF BRAKING 1.25 " " " " "
COASTING 40 SEC.
TIME OF STOP 30 "
KW. AT POWER STATION INCLUDES:
TRAIN LIGHTS AND AUXILIARIES FOR 3 HOURS PER DAY 4.8 KW. PER 100 TONS
TRAIN HEATERS FOR 3 MONTHS 41.7 KW. PER 100 TONS
AVERAGE SPEED INCLUDING 30-SEC. STOP
ANNUAL AVERAGE KILOWATTS PER 100 TONS AT POWER STATION
AVERAGE KILOWATTS PER 100 TONS AT TROLLEY, TRACTION ONLY
ANNUAL AVERAGE WATT-HOURS PER TON-MILE AT POWER STATION
AVERAGE WATT-HOURS PER TON-MILE AT TROLLEY, TRACTION ONLY
0
10
20
30
40
50
60
70
80
MAX. SPEED, MILES PER HOUR, ON STRAIGHT AND LEVEL TRACK
WATT-HR. PER TON MILE
100
90
80
70
60
50
40
30
20
10
0
AVERAGE KILOWATTS
250
200
150
100
50
0
MILES PER HOUR
50
40
30
20
10
0

FIG. 7.

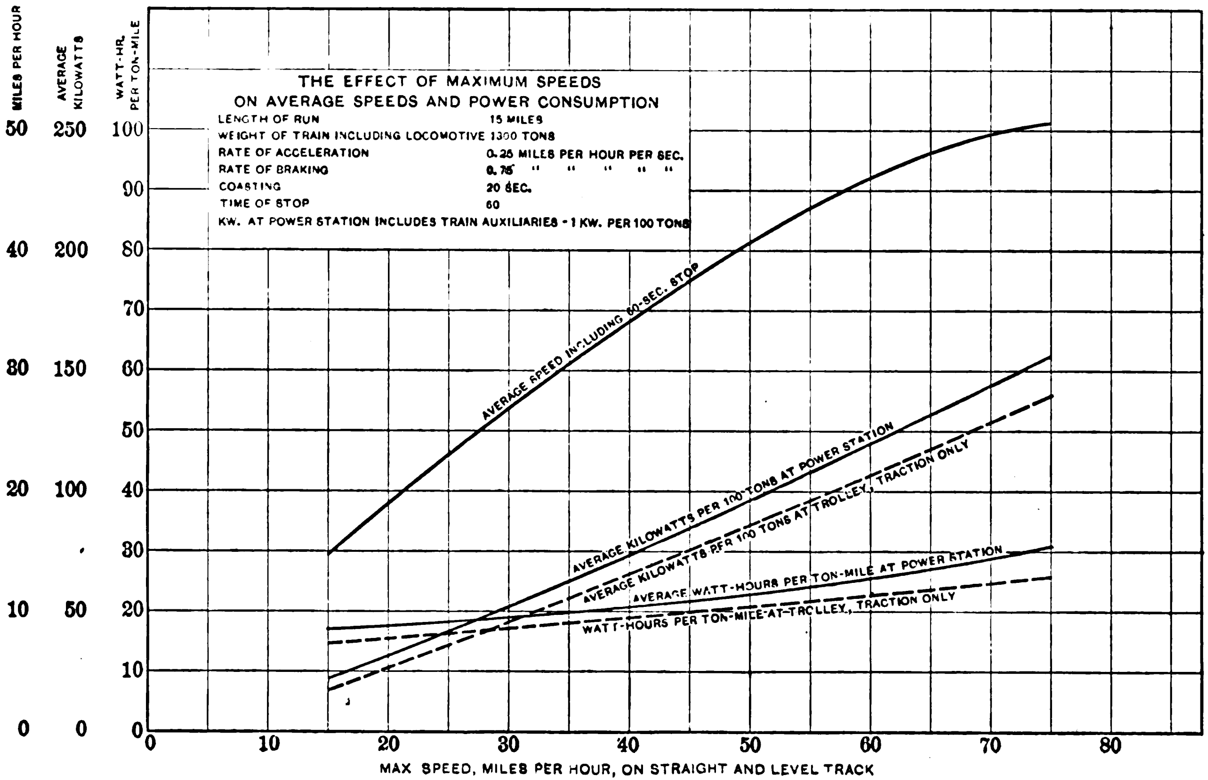
THE EFFECT OF MAXIMUM SPEEDS
ON AVERAGE SPEEDS AND POWER CONSUMPTION
LENGTH OF RUN 15 MILES
WEIGHT OF TRAIN INCLUDING LOCOMOTIVE 1300 TONS
RATE OF ACCELERATION 0.25 MILES PER HOUR PER SEC.
RATE OF BRAKING 0.75 " " " " "
COASTING 20 SEC.
TIME OF STOP 60
KW. AT POWER STATION INCLUDES TRAIN AUXILIARIES - 1 KW. PER 100 TONS
AVERAGE SPEED INCLUDING 60-SEC. STOP
AVERAGE KILOWATTS PER 100 TONS AT POWER STATION
AVERAGE KILOWATTS PER 100 TONS AT TROLLEY, TRACTION ONLY
AVERAGE WATT-HOURS PER TON-MILE AT POWER STATION
WATT-HOURS PER TON-MILE AT TROLLEY, TRACTION ONLY
MILES PER HOUR
50
40
30
20
10
0
AVERAGE KILOWATTS
250
200
150
100
50
0
WATT-HR. PER TON-MILE
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
MAX SPEED, MILES PER HOUR, ON STRAIGHT AND LEVEL TRACK

FIG. 8.

Referring to the table, the average cost of this item for 5 years, viz., 11.292%, would be reduced by electric traction to 5.533%.

Item 23. "Water supply for locomotives." This item is eliminated if electricity be substituted for steam.

Item 24. "Oil, tallow, and waste for locomotives." This item should be considerably reduced. We assume that it will be reduced to 0.25%.

Item 25. "Other supplies for locomotives." We make no change in this item.

Item 26. "Train service." This item is not changed.

Item 27. "Train supplies and expenses." This item among many others includes the following which will be changed by the substitution of electric motive power, viz.: "Heating, lighting, cleaning and lubricating cars, including the cost of supplying and pumping gas into cars."

In discussing Item 22, we have included in the estimate of electric power required energy sufficient to light all cars three hours out of every twenty-four. We have also included energy sufficient to heat all passenger trains by electricity an average of three months per annum. Both of these are important items. The cost of cleaning the cars should also be reduced by the elimination of smoke and cinders from the locomotives. All things considered we believe it is fair to assume that under electric operation this item will approximate one per cent. of operating expenses.

Item 28. "Switchmen, flagmen, and watchmen" will not be changed.

Item 29. "Telegraph expenses." In general it is not to be expected that the large amounts of power required for train operation can be transmitted electrically under conditions which make it necessary to parallel telegraph lines by power circuits without more or less interference with the telegraph and telephone service. Certain technical questions in regard to methods of preventing interference remain to be worked out. The erection of overhead circuits carrying power supply will involve generally more or less shifting of the location of the telegraph lines. This item of expense is taken care of in our estimate by inclusion of the cost of overhead construction, and is treated as a capital account.

Telegraph circuits being rearranged with reference to the power circuits, or equipped with one or another of the devices which have been suggested as preventives of difficulties resulting from inductive effects of the power circuits, it might be assumed, perhaps with safety, that Item 29 would not be changed, but we are inclined to the opinion that there will be a slight increase in the cost of this item even under the best plans heretofore proposed, and we therefore increase it in our estimate to 0.2%.

Item 30. "Station service." Examination of the factors constituting this large item indicates no material change.

Item 31. "Station supplies." This item includes among many others the following, viz., "All expenditures for account of heating and lighting depots, waiting rooms, freight and passenger offices and other station buildings; fuel and supplies for engines operating freight carriers on docks, wharves and piers to convey freight between boats and cars; supplies used for stations and yards, signal lights, street lights, switch lights, semaphore lamps, etc., also bills of municipalities for lighting highway crossings."

The ability to employ conveniently for the lighting of important passenger stations and yards, electricity delivered at the point of consumption at a cost which, exclusive of capital charges upon power plant, closely approximates 0.6 cent per kilowatt-hour, to substitute electric motors for engines now used to operate freight carriers on docks, wharves, and piers, and to avail conveniently of electric hoists and telpher systems all these are important advantages incident to the adoption of electricity. For lighting and incidental power service of this kind, equivalent to that with which railroads are now apparently satisfied, the change would undoubtedly mean reduction in cost. We will let it stand as it is, however, and would point out the fact that without increasing the cost of this item, a great improvement in facilities for handling freight at docks and wharves and for lighting passenger stations and yards will result from the substitution of electric power.

Items 32, 33, and 34. viz, "Switching charges, balance," "Car per diem and mileage, balance," and "Hire of equipment, balance," will not be changed.

Item 35. "Loss and damage," Under this item the important factors which will be affected by the substitution of electricity for steam are the following: viz., "Charges for loss, damage, delays or destruction of freight, parcels, express matter, baggage and other property entrusted for transportation (including live stock received for shipment) and all expenses directly incident thereto. * * * Charges for damages to or destruction of crops, buildings, lands, fencing, vehicles, or any property other than that entrusted for transportation, whether occasioned by fire, collision, overflow, or otherwise; also services and expenses of employees or others while engaged as witnesses in the case of suits."

For reasons which have been referred to in our discussion of the subject " Safety," it is clear that there should be a material reduction in the charges for loss due to destruction of freight, etc.

Another saving will result from the practical elimination by reason of damage of fire, which now not infrequently is caused by sparks from locomotives.

These savings will be offset to some extent by damage due to telegraph, telephone, or other wires coming in contact with the power circuits of the railway, unless reasonable care be exercised in preventing such accidental contact by the adoption of proper precautions when the electric equipment is installed.

In our estimate we have reduced item 35 to 0.75%.

Item 36. Injuries to persons." " This account includes all charges on account of employes or other persons killed or injured except lawyers' fees and court expenses."

For reasons referred to under the heading "Safety" some reduction in the number of passengers and employes killed and injured in railway accidents may be expected to result from the use of electricity. The risk of fire following collision being materially reduced, we should anticipate a relatively greater reduction in the number of passengers and employees killed in accidents caused by collision or derailment than in the number injured and a reduction in the average severity of non-fatal injuries may also be expected. On the other hand, a certain number of deaths and injuries will result directly from the use of electric power in large amount, by accidental contact with charged conductors. These accidents, however, should not be frequent if care is taken in the installation and proper maintenance of the electric equipment.

In the year 1904, of 10,046 fatal casualties reported by the Interstate Commerce Commission " 3,632 were sustained by employes, 441 by passengers and 5,973 by other persons. Of this last number 5,105 were reported as trespassing, from which it may be presumed that the railways are in no sense legally responsible for the deaths in question; suicides are included in this class."

"The number of injuries sustained by employees during the year was 67,000. The number of injuries sustained by passengers was 11,111 and the number of injuries sustained by persons other than passengers and employees was 7,977."

As regards the expenses included under item 36, we have no data indicating how these are divided other than the fact that the railroads apparently were put to little if any expense on account of about 80% of those persons other than passengers and employees who were killed and injured. While it is probable that a large part of the expenditures were on account of passengers killed and injured, and while any reduction in fatal and serious accidents to passengers therefore would materially affect this item, we have thought it best in the absence of satisfactory data to leave it practically as it stands, our estimate being 1%.

Item 37. "Clearing wrecks." In our opinion this item will be reduced under electric operation for reasons which have been sufficiently indicated in what we have said in regard to item 35. It would seem that 0.2% is a fair estimate of its probable amount.

The following items will not be changed:

Item 38, "Operating Marine Equipment."
Item 39, "Advertising."
Item 40, "Outside agencies."
Item 41, "Commissions."
Item 42, "Stock yards and elevator."
Item 43, "Rents of tracks, yards and terminals."
Item 44, "Rents of buildings and other property."
Item 45, "Stationery and printing."
Item 46, "Other expenses."

GENERAL EXPENSES

As regards the several items included under the heading "General expenses," the adoption of electricity will cause no material change.

Our approximate estimate of the expenses chargeable to operation if electricity were in use to-day for the operation of all the railways in the United States, as discussed in the foregoing pages, is recorded in detail, item for item, in the last column of the tabulated data in Table I; these data with the exception of this column of estimates being the official records of the reports of the Interstate Commerce Commission. When considered in detail, the estimates are naturally subject to criticism more or less destructive, as in respect to many items we have not found opportunities to secure and investigate the great mass of detailed data showing in segregated form the scores of factors which are included in the aggregates appearing as single items in the summarized table of operating expenses; but while recognizing fully the imperfections and incompleteness of the attempted comparative analysis, we believe that the conclusions reached are correct within a reasonable degree of approximation.

According to our estimate, if all the railways of the United States were to-day operated by electricity using the single-phase alternating-current system at the potential adopted for the equipment of the New Haven Railroad, the energy required for operation being developed by power plants such as are to-day in extensive use and transmitted at potentials well within limits established in practical service, and if the rolling stock equipment consisted of locomotives and multiple-unit trains fitted with motors and control apparatus no better than the best which now exist, the aggregate cost of operation which in 1905 amounted in round numbers to $1,400,000,000, would be reduced by about $250,000,000.

To accomplish this result, power plants delivering about 12,500,000,000 kilowatt-hours per annum would be required. Assuming the radius of transmission from power houses to be 150 miles, the load-factor in railway service should be not less than 0.75, and taking this figure it appears that power plants capable of delivering a maximum output of about 2,800,000 kilowatts will be sufficient to operate the entire railway service of the United States as existing in the year 1905. The average output required is about 10 kilowatts per mile of line and 7 kilowatts per mile of track.

In 1905 the average gross earnings of our railroads per mile of line were $9,598, and the average operating expenses $6,409. The foregoing calculations lead to the conclusion that high-class electric equipment now available would reduce this average cost to $5,265. The difference is $1,144 per mile of line, against which apparent saving must be charged the annual interest and depreciation of the power plant, the addition to permanent way equipment, comprising overhead construction and track bonding, the transmission circuits, and the sub-stations with their equipment. Assuming 5% interest on cash cost of these items and allowing 5% for a sinking fund to cover depreciation of power house with its equipment and 2½% for a sinking fund to cover depreciation of the overhead construction and distributing system, the aggregate of fixed charges works out at $837 per mile of line. The saving in operating expenses, therefore, is more than sufficient to take care of the increase of fixed charges. In other words, it appears that the entire railroad system of the United States could be operated to-day at less cost by the electric motor than by the steam locomotive. That the railroads in general if so equipped would realize a large increase in earning power will be admitted by all who have given the subject intelligent attention.

In charging against electric operation 5% upon cost of power plant and 2.5% upon overhead construction, transmission circuits, substations, and track bonding, we have departed from methods usually adopted in financing of American railway properties. If no depreciation be charged against the increased capital account represented by the items named, the apparent saving will be materially increased.

While our estimates have led us to the conclusion that, under average existing conditions of railway operation in the United States, improved financial results would be attained by the substitution of the electric motor for the steam locomotive, the immediate and general adoption of the new motive power by our railroad companies is neither possible or desirable. It requires no argument to demonstrate the wisdom of making haste with deliberation in a matter involving interests of such magnitude as those which are tied up with the transportation systems of the United States. Recognizing the magnitude of these interests and having in mind the fact that the art of electric traction as applied upon a large scale to heavy train units is yet young, the point which we desire here to emphasize is the necessity of conservative and carefully considered action upon the part of all members of this Institute who may be called upon to advise in respect to the electrification of railways now operated by steam.

Referring to the following tabulated results, in which we have applied the estimated reductions in operating expenses under electric traction, amounting to 18% of the present average operating expenses to the ten geographical groups into which the railroad systems of the United States are divided by the Interstate Commerce Commission, the relatively great advantages of applying electric traction to systems operating heavy traffic showing large gross earnings per mile of line are evident at a glance.

TABLE II.

COMPARISON PER MILE OF LINE—BY GROUPS STEAM AND ELECTRIC OPERATION.

(216,974 Miles Represented.) (Dollars per mile of line per year.)

Group No.	General Location	Miles of Line Represented	Gross Earnings	(Steam) Operating Expenses	(Electric) Operating Expenses	Difference Steam and Electric Operation	5% interest on Electrical Equipment Excluding Rolling Stock.
I	New England	8,094	$14,511	$10,493	$8,604	$1,889	$647
II	New York, Pa., et al.	23,281	20,752	13,671	11,210	2,461	790
III	Ohio, Ind., Mich	25208	12,483	9,198	7,542	1,656	640
IV	Virginias, N. and S. Carolina	12,542	7,359	4,590	3,764	826	484
V	Kentucky, Fla., Louis, et al.	24,563	6,867	4,899	4,017	882	475
VI	Ills., Wis., Dakotas, Ia., et al	48,672	8,021	5,169	4,239	930	525
VII	Mont., Neb., and Wyoming	11,546	7,737	4,092	3,355	737	461
VIII	Colo., Ark., Missouri, et al	30,456	6,362	4,308	3,533	775	461
IX	Texas and New Mexico	14,875	5,588	4,108	3,369	739	445
X	Pacific States	17,737	8,439	4,880	4,002	878	464
	United States, Total	216,974	9,598	6,409	5,255	1,154	516

THE STANDARDIZATION OF ELECTRIC RAILWAY TRACTION EQUIPMENT

Electricity, entering the field hitherto occupied exclusively by the steam locomotive, encounters conditions which greatly emphasize the necessity of prompt standardization of engineering practice. The management of our railways, beginning by electrifying terminals, tunnels, and mountain-grade divisions, will inevitably be led to extend these zones of electrification until they include divisions of very considerable length, and even trunk-line systems. To call attention to the transcendent importance of standarizing the location of such additions to permanent way equipment as the overhead trolley conductor and the third rail, is to demonstrate its necessity.

Electrical engineers now generally recognize the great value of established standards of frequency and potential in plants installed for lighting and power purposes. In recent years, the Institute, through its Standardization Committee has done splendid work for the manufacturer of electrical apparatus, as well as for the investor, by using its influence to promote the adoption of standards. Not many years ago, however, manufacturing companies, and consulting engineers, were in many cases prone to put forward or specify apparatus without reference to its ability to operate effectively in conjunction with other central station equipment, even when the latter was in actual operation in the immediate vicinity of the new plant. Fortunately, this tendency was less marked in the United States than it was, for example, in Great Britain. What will happen from a failure to adopt standards of practice at an early stage in the development of an industrial art of this nature, is well illustrated by the problem now presented in London, where the engineering advisers of the London County Council are engaged in studying the problem of how to supply electricity in bulk to 62 central-station plants producing electricity in bewildering variety of frequency and potential.

In the railway field, obviously, general principles are the same as in lighting; but wise foresight is more necessary and failure to exercise such foresight at this date less excusable. Moreover, the advocates of electric traction, unlike those who introduced the electric light into commercial service, are called upon to deal with a great body of trained engineers and experienced managers who are engaged in operating and extending systems of transportation which challenge admiration and respect. The rolling stock equipment of our railways, as a whole, is justly an object of national pride. The engineers and managers directing and controlling these properties are probably the equals of any body of men in the world as regards intelligence and experience. Obviously, it is of the utmost importance that they who accept the responsibility involved in the substitution of electricity for steam in the operation of certain parts of our great railways, should avoid fancies or fads and should in every way coöperate in the great work of evolving promptly standards of electric railway practice which shall withstand the test of time. The comparatively small beginnings of to-day will in all probability extend with a rapidity which we cannot now realize, and the confusion and loss which will inevitably result in the near future, if a variety of electric equipment be grafted at different points upon the existing railroad systems now operating by steam, may be imagined. The trouble and expense caused some years ago by the existence of several gauges of railway track in America were as nothing compared with what may result from a failure to establish promptly stanards of practice in the field of electric railway traction.

Where to-day are the "16,000 alternation" system of lighting, the " 15,000 alternation " system of lighting, the " constant-current alternating-current arc light system," the " 40-cycle system " and the " monocyclic system?" Where ten years from to-day will be the 1200-volt, or the 1500-volt, direct-current systems which have been suggested as substitutes for high-potential alternating-current systems in heavy electric traction?

While emphasizing the great importance of the early establishment of standards in the field of heavy electric traction, it must be recognized clearly that further inventions are liable at any time to modify views based upon present knowledge. The work of standardizing, therefore, should proceed with caution; but surely if present knowledge, not only of existing apparatus but of the lines along which applicable improvements must take place, is not sufficient to justify conservative application of the principle of standards, it is not sufficient to justify the investment of the very large sums which are now being expended for electric equipment.

Engineers constituting the membership of this Institute owe it to themselves, as well as to their clients, to use every effort without prejudice and without fad, to prevent waste by opposing the introduction of apparatus which, from its limitations, cannot solve the general problem of railway electrification; and it is to be hoped that they will use their united influence to fix proper standards as rapidly as this establishment may be consistent with progress.

Fortunately, knowledge of the possibilities and limitations of electric apparatus to-day is a very different thing from what it was in the early days of electric lighting. At the present time we have available theory so complete that electric science is less exact only than the science of astronomy and in applying this science in constructive work agreement between results carefully predetermined by calculation and those realized in practice is far closer than in any other comparable branch of engineering. There can be no doubt that it is possible to-day, in passing upon such a question, for example, as that of best frequency for railway operation to make a choice which shall withstand the test of time.

The necessity of proper standardization is obvious. Specifically, it would seem feasible and eminently wise to agree upon standards of practice in respect to the following:

a. Location of third rail.

b. Location of overhead conductor used with single-phase alternating-current system.

c. Frequency of alternating-current traction systems.

It is equally desirable, but probably less easy, to agree upon a standard system of multiple-unit control for train operation.

THE QUESTION OF FREQUENCY.

While appreciating throughly and desiring to emphasize the importance of establishing and maintaining standards, it is also of the greatest importance that standards should be wisely chosen. The choice should be made, if possible, with full knowledge of the essential factors involved, and correct perspective view of their relative importance. It is with the feeling that so far as the frequency 25 cycles per second may be said to have become established, considerations obvious at first glance, but not properly controlling, may have influenced the choice unduly that we desire to present for discussion, the very important question whether 25 cycles per second or a lower frequency; *e.g.*, 15 cycles per second, is best adapted and should be established as a standard in the equipment of railways by electricity.

Final decision of such a question should be left neither to manufacturing companies, the management of which may be unduly influenced by commercial considerations, affecting its own immediate prosperity or convenience, nor should it be left to the individual consulting engineer. It is precisely the kind of question which the Institute should pass upon by the adoption of a recommendation carefully considered by its Standardization Committee. The manufacturing companies, which are largely and very influentially represented in the body of the Institute, will doubtless be willing to coöperate in the collection and study of the facts requisite to the formation of a well-grounded report.

While the adoption of a standard by the Institute has the force only of a recommendation, the American Railway Association perhaps might deem it wise to indorse the choice of the Institute. Such action on the part of these two bodies would go far definitely to establish the standard.

Comparing the relative advantages of 25-cycles and 15-cycles in railway service the salient advantages of the former are the following:

1. It is to-day in extensive use in plants developing and distributing energy for lighting and power purposes, and through sub-stations equipped with converters for the operation of many interurban lines. It has been adopted on a very large scale by such companies as the Interborough Rapid Transit Company of New York for the operation of its subway, surface, and elevated lines, by the Pennsylvania & Long Island Railway Companies for the electrification of New York terminal service and operation over a considerable part of Long Island, and by the New York Central for the electrification of its terminal service It is also the frequency developed by all of the great power plants at Niagara Falls, and from this source of power it is possible for all railway lines within a radius of 150 miles, or an even greater distance, to procure an ample supply of very cheap power.

It has been adopted by the New York, New Haven & Hartford Railway Company, the pioneer among American railroads in the adoption of the alternating-current motor in heavy railway traction, and by the Grand Trunk Railway for the electrification of the Sarnia Tunnel. Alternating current at 25-cycles is also utilized without the interposition of converters by the motor equipment on a dozen or more interurban trolley lines.

2. Our great manufacturing companies have drawings, patterns, and dies which enable them to manufacture conveniently and promptly practically all power-house and sub-station equipment required for 25-cycle apparatus. The weight of this consideration, however, is somewhat lessened by the fact that the march of progress—just now greatly accelerated by the general adoption of steam turbines—will undoubtedly cause a large proportion of existing drawings and patterns to be superseded probably in the very near future and certainly within the next five years.

3. The 25-cycle system is preferable to the lower frequency in the design of turbo-generators, since it affords wider range within which to select speed for units of various outputs. For very large units a frequency of 15-cycles, for example, requires either a 2-pole generator operating at 900 rev. per min., a 4-pole generator operating at 450 rev. per min., or a 6-pole generator operating at 300 rev. per min. Reduction in the number of revolutions per minute implies increase in diameter of the revolving element of generator and turbine, and in machines of large output the diameter of the revolving element in turbines of certain types may become too large for shipment in view of the limitations imposed by tunnels.

4. A frequency of 25 cycles permits convenient and effective lighting of yards and shops by incandescent lamps. It is also more favorable than a lower frequency as regards operation of induction motors for shop purposes.

Should our railways in general be equipped for electric operation, it is to be expected that in many cases they would undertake to supply electricity for light and power purposes beyond their own requirements, and the higher frequency possesses important advantages with reference to such commercial service.

For lighting and general power purposes in cases where service for lighting purposes that shall be thoroughly satisfactory in respect to voltage, regulation and continuity is requisite, commercial supply at 25 cycles would be preferable. Through the interposition of motor-generator sets or converters in combination with storage batteries in such cases either frequency is applicable.

5. The higher frequency possesses some advantage in respect to the ratio of tractive effort to weight upon drivers. The best information available to date appears to indicate that the difference between 25 cycles and 15 cycles in respect to

this consideration probably approximates 10%. Further data from actual test are desirable, and must be obtained before it is possible to estimate closely the weight of advantage possessed by the higher frequency.

6. The higher frequency is preferable for induction motors in railway service requiring a considerable range of speed adjustment. The force of this consideration depends upon the probability of using induction motors for traction purposes, and applies not only to the excellent three-phase motors, such as are in very successful use upon the Valtellina line, but also to the single-phase induction motor which, perhaps, is not beyond the range of probability. It is probable that in any general electrification of our railway system, induction motors will play a part by no means unimportant.

Without attempting detailed discussion, it is evident from the foregoing brief statement of the more important considerations in favor of 25 cycles that extremely weighty reasons must exist if the adoption of a lower frequency, *e.g.*, 15 cycles, is justified.

While our object in raising this question of frequency is to present it for discussion with a view to securing additional data and, if possible, a careful consideration of this very important question by the Institute through its Standardization Committee, or a special committee, and while we desire to avoid anticipating the verdict resulting from such an investigation, it is proper to state here that consideration of the facts now available leads us to conclude that notwithstanding the number and force of the arguments in favor of 25 cycles, a frequency of 15 cycles is preferable and should be adopted for heavy electric traction. The fundamental and, as it would appear, controlling reason which leads to this conclusion is the fact that within given dimensions a materially more powerful, efficient, and generally effective single-phase motor can be constructed for 15-cycle operation than is possible if 25 cycles be selected.

Final decision of the question whether the advantages of the 15-cycle motor as compared with the 25-cycle motor in respect to dimensions, weight, efficiency, power-factor, and commutation are such as outweigh the many and important considerations which favor the higher frequency, requires more complete data than we have been able to secure up to the present time. That the difference is material, however, is established not only by general theoretical considerations of the effect of a reduction in frequency upon the design and performance of single-phase commutating motors, but also by the following facts:

1. In the case of multiple-unit equipment of passenger cars where locomotives are dispensed with and motors carried upon the car trucks, it is very important that the dimension of motors be reduced to a minimum. Cars weighing, say, 35 tons without equipment and operating on straight and level track at speeds of from 60 to 70 miles an hour, require but two motors, except as it may become necessary to employ four motors by reason of lack of sufficient clearance at cross-overs. The difference between a two-motor equipment and a four-motor equipment in such a case approximates $2,500.00 per car, besides which the four-motor equipment adds materially to weight, practically doubles complication, and, for both of these reasons, increases cost of operation. The difference between the dimensions of a 15-cycle and a 25-cycle motor may easily be the controlling consideration compelling the adoption of the four-motor equipment.

2. In the application of single-phase commutating motors to locomotives in general railway service, the minimizing of motor dimensions is perhaps still more important, although in this instance the limitations imposed by the space available are less obvious.

High-speed passenger locomotives at least should be gearless. For any assumed limits of weight per axle and length of wheel-base, that frequency is preferable which permits the construction of a motor which will exert the greater pull at the draw-bar, provided efficiency, commutation, and power-factors are substantially equal.

Those who are engaged directly in the design of single-phase motors are probably in position to contribute to the discussion of this paper data which will throw much light upon the subject; but it would seem probable that within given limits of dimensions, 15-cycle motors would materially surpass 25-cycle equipment in this respect. We are inclined to this opinion notwithstanding the probable advantage of 25-cycle equipment as regards the ratio of effective draw-bar pull to weight upon drivers.

3. There can be no question of the superiority of the 15-cycle motor in respect to the very important features, commutation, efficiency, and power-factor. Efficiency is obviously and directly important. Power-factor affects the efficiency of the

entire system from the motor to, and including, the generator. Commutation, in view of the large and expensive commutators and the brush complication of this type of motor, is of great importance.

In order that the question raised may be looked at in proper perspective the following estimates based upon foregoing calculations will be useful:

For the equipment of the entire railway system of the United States as now existing an aggregate power-house output capable of supplying continuously 2,100,000 kilowatts would be required. Of the electric apparatus installed in the power-houses, a change in frequency affects the generators, transformers, and a large proportion of the measuring and indicating instruments. It also affects the cost of the engine or turbine employed to drive the generator. At 25 cycles, the apparatus affected by frequency should cost approximately $30 per kilowatt. At 15 cycles it would cost on the average perhaps $33 per kilowatt. Cost of sub-station transformers would be increased approximately one-third, and, in round numbers, the total cost of turbines and electrical power house and sub-station apparatus would be increased from $70,000,000 to $80,000,000.

If it be assumed that one electric locomotive will do the work of two steam locomotives, about 24,000 electric locomotives would be required to take care of the present railway business of the country. Assuming the cost of the average electric locomotive to be $25,000 the aggregate cost of locomotives required would be $600,000,000. Allowing for the increased cost of the 15-cycle transformers, it would seem that the difference in cost of the average locomotive should be not less than $1,000 in favor of the lower frequency, or for 24,000 locomotives $24,000,000. This is more than twice the estimated difference in cost of power-house and sub-station equipment.

It seems entirely safe to say, therefore, that the aggregate first cost of electric equipment and of steam turbine will be decreased by a change from 25 cycles to 15 cycles. The operating cost will obviously be decreased very materially. At least three-fourths of the above estimated cost of electric locomotives, say $450,000,000 represents cost of electric equipment. It will be seen, therefore, that of the apparatus which our electrical manufacuring companies may be called upon to furnish, more than 85% is rolling stock. Obviously, any argument in favor of 25-cycle equipment which may rest upon existence of drawings and patterns and convenience in manufacturing should have comparatively little weight.

The use of 15 cycles instead of 25 cycles also secures considerable advantage in respect to the overhead trolley conductor and track return. With a given limit of voltage-drop, this advantage may be utilized by reducing size and, consequently, the cost of the overhead copper and the copper used to reinforce the track return.

Under the plans which we have assumed as a basis of our calculations, the amount of copper required for feeder circuits, trolleys, and reinforced track-return, estimated at 20 cents per pound would cost approximately $750,000,000 were the entire railway system of the country as existing in 1905 to be equipped for electric operation.*

We desire to acknowledge with appreciation, assistance kindly rendered in the collection of data for this paper by Mr. J. M. Graham, vice-president of the Erie Railroad Company; Theo. N. Ely, chief of motive power of the Pennsylvania Railroad Company; Mr. George Gould; Mr. E. P. Bryan, vice-president and Mr. Frank Hedley, general manager, of the Interborough Rapid Transit Company; Mr. G. Leve, of the Railway Electric Power Company; Mr. Alvan Markle, president of the Wilkes-Barre & Hazleton Railway Company; Mr. George C. Smith, vice-president of the Security Investment Company; Mr. H.J. Pierce, president of the International Railway Company; Messrs. Conwell, Shepard and McLaren, of the Westinghouse Electric & Manufacturing Company; and Messrs. Potter and Mahony, of the General Electric Company.

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*In all our estimates we have included 0000 copper conductor in the return circuit, this being bonded to the rails at intervals for the purpose of preventing dangerous potential on track in case of a broken bond.

A paper presented at a Meeting of the Pittsburg Branch of the American Institute of Electrical Engineers, November 20, 1906.

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WIRELESS TELEGRAPH RECEIVERS

BY S. M. KINTNER

Improvements in wireless telegraph receivers have been much more numerous than in the sending apparatus. Since the first detector of Hertz, consisting of a minute spark-gap and loop of wire, used in 1887, there has been a very marked improvement. This improvement has not extended to the sending apparatus, for this apparatus is practically the same to-day as that employed by Hertz, differing mostly in magnitude and in the fact that one side of the oscillator is connected to ground.

Of the various detectors, the coherer is perhaps the best known. It was this device that gave wireless telegraphy such an impetus. Marconi used it in nearly all of his early work. The coherer, it is well known, operates by the breaking down of insulating films separating small metal particles. It is thus evident that the coherer is dependent upon voltage for its operation, the quantity of current involved entering only as a secondary function. The coherer can be looked upon as a sensitive trigger, delicately set, which after operating requires to be reset before it is ready for the next impulse. It is a delicate and treacherous device, and, is usually set aside by investigators just as soon as they have any other device to substitute for it.

In 1899, Professor Fessenden and the writer were conducting some wireless telegraphy experiments, and during these investigations the writer tried to persuade Professor Fessenden to try a coherer in some of the tests, but he was unwilling to do so. He remarked at that time, when every one was singing the praises of the coherer as such a remarkable and satisfactory instrument, that it was a waste of time to use it, as it was incorrect in principle. He advocated then some form of current-operated device, a device which would utilize more of the collected energy than was possible with the coherer. In these early experiments, a form of galvanometer consisting of a small ring suspended at an angle of 45° to the plane of two field coils, as shown in Fig. 1, was employed.

This device was connected in the receiving circuit, forming part of a straight series circuit from the vertical antennae to ground. When the oscillating currents set up by the radiating electric waves were passing through the field coils *F*, *F*, a current was induced in the ring *R*. The ring would then tend to move and thus give indications of the presence of electric oscillations in the vertical wire. The amount of the deflections would be read with a reading telescope and scale from a mirror carried on the ring, as with an ordinary galvanometer.

This device gave quantitative results, while those obtained with the coherer were entirely qualitative and quite uncertain. Working with a device of a kind capable of giving quantitative values, even though possibly not so sensitive, was much better for studying various modifications of the sending apparatus, etc. With that old home-made instrument, some of the fundamental points that have since become standard practice were determined.

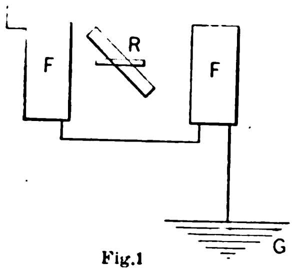

Fig. 1

Unfortunately for the ring-form of galvanometer, it had one serious defect; the current in the ring was in nearly 90° phase-relation with the magnetic field producing it, resulting in a very small torque. But for the fact that the ring itself had an appreciable inductance for its own induced current, thus causing it to lag slightly, there would have been no torque. Attempts were made to increase the torque by various schemes calculated to change the phase of the induced currents, but with only moderate success. Very small iron wires were placed through the ring at right angles to the main field, thus tending to increase the inductance of the ring. In other trials the ring was split and terminated in small condenser plates, but with no material improvement.

After Professor Fessenden had left Pittsburg to devote all his time to investigating wireless telegraphy, the writer attempted for a time to carry on some investigations along similar lines In attempting to overcome the trouble with the ring and its phase-relation, an effort to produce a rotary field was partly successful. Fig. 2 indicates the method used to produce this field.

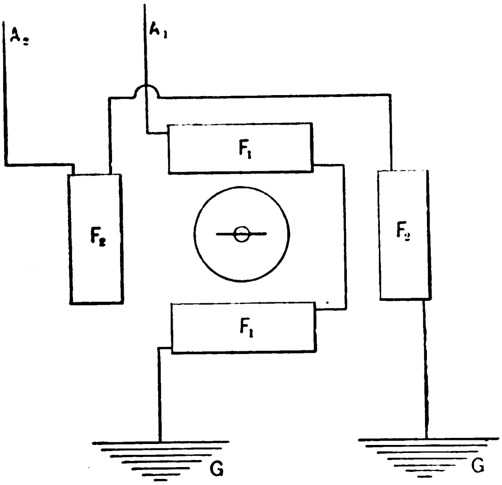

Fig.2

It will be seen here that a two-phase field is arranged and if currents of the proper phase are sent through it, a true rotary field will be produced. The two-phase currents were obtained by spacing two vertical antennae one-quarter wave-length apart It was thus possible to tell the direction the waves were coming, as of course the direction of rotation depended upon which of the two verticals reached its maximum value first. The device was not very sensitive, probably because the field could not be so advantageously arranged as is desirable for induction motors. An effort to utilize exceedingly fine wire to concentrate the field proved a complete failure.

Marconi brought out a magnetic detector which operated on the peculiar physical fact that iron when passing slowly through its hysteresis loop, is very sensitive to a magnetic field set up by electric oscillations. This device is quite successful in service and is much more reliable than a coherer. In practice this device is arranged so that a small motor is rotating an iron core at a very slow rate in a magnetic field; the core is surrounded by the detecting loop connected in the receiving circuit; a secondary loop leads to a telephone, and the sudden changes in magnetic conditions of the iron due to electric oscillations set up by the received waves are indicated by small current changes in the telephone circuit.

Fessenden brought out what he called a hot-wire barretter that was quite an advance, particularly for quantitative work.

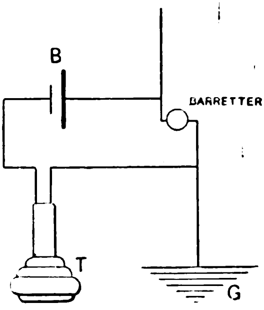

Fig. 3

This device has since been used for some investigations in telephone work and is very satisfactory for such service. The device consists of a very small loop of platinum wire, so arranged in a circuit that its change in resistance due to change in temperature caused by the oscillating currents is indicated in a telephone connected in circuit as shown in Fig. 3.

The size of the platinum wire and some of its characteristics are quite interesting. The small wire in the loop is only about 0.00003 in. in diameter and only about 0.015 in. in length. These figures seem almost incredible, but they are approximately correct. Such error as really exists is on the side of too large dimensions.

The Wollaston wire, by which name the above is known, is a composite wire of silver with a platinum core. The platinum is first drawn as small as possible and then coated with silver until a composite wire is formed having a section of which 99% or more is silver. This composite wire is then drawn down to very small dimensions, the platinum core being reduced in section at the same time. The silver is afterwards dissolved in acid at the places at which the fine section is desired.

An 0.00008 in. platinum wire has a resistance of 8450 ohms per foot, or approximately 10.5 ohms for 0.015 inches in length. The small mass involving, only 7.5 x 10^{-11} cubic inches of platinum requires only 0.0353 ergs to raise its temperature 1° cent., or one erg would increase its temperature about 30° cent., which would mean a change in resistance of approximately 12%. The above figures are assumed without consideration of the larger section of wire at the ends of the loop where the silver has not been removed. Unfortunately for the sensitiveness of this device, these terminals play a very important function, and tend to keep the temperature down, so that instead of a 12% resistance change it is quite likely that not more than 6% change in resistance really takes place. With such a small mass, its thermal capacity is very low, and it is thus able to follow changes of temperature at a very rapid rate. The device actually responds so rapidly that no trouble is experienced in distinguishing between the quality of several sparks, in the same way that one can distinguish each of several voices.

The drawbacks with this detector are, its liability to burn out and the difficulty of renewals. Burn-outs may result from lightning or from signals of great intensity. The forming of the loop is a very delicate operation and is done under a microscope.

The liquid barretter was the next important advance made in detectors. The liquid barretter differs from the preceding only in that an exceedingly fine liquid resistance is substituted for the metal resistance. This liquid resistance is best made by making use of the Wollaston wire again, and allowing it to dip for a very slight distance into an electrolyte. The electrolyte used is preferably a 20 to 30% solution of nitric acid. The acid serves to dissolve the silver and thus keep the barretter in operating condition should it become burned out by excessive currents.

It is a well known fact that the resistance between two concentric cylinders immersed in an electrolyte is equal per unit length to $\frac{C \log.}{2\pi} \frac{b}{a}$ where *C* is the resistivity of the electrolyte and *b* and *a* are the diameters of the two cylinders respectively. It will be seen very readily from the above formula that nearly all the resistance is located in the liquid surrounding the fine wire. Electrolytes have much larger temperature coefficients than metals, and thus a decided increase in sensibility is gained. In addition to the ohmic resistance change, there is a change in the polarization of the fine metal point. Fortunately, these are additive effects and tend towards sensibility.

The liquid barretter was discovered accidently by Professor Fessenden while making some loops for the wire form of barretter. He noticed that a delicate current meter in the circuit with the loop that was having its silver dissolved off,. was fluctuating in synchronism with a sending station some distance away. An investigation of the cause revealed the fact that the wire loop had broken and left two fine points dipping into the acid. That was the first form. Later tests showed that one point was supperior to two. Other than that, the principle development consisted in getting a good mechanical arrangement and testing a number of electrolytes. Nitric acid, as mentioned above, has proved the best, everything considered, though several other solutions such as H Cl, K O H, H_2SO_4, have been satisfactory.

This detector is the best that has thus far been developed. A number of detectors are at present in use which are fundamentally the same as the liquid barretter. The fact that it has so many imitators is evidence of its good qualities.

One of the most notable detectors, a modification of the barretter, is that one in which the battery is made a part of the detector by using a containing cup made of a metal electrochemically positive to the fine platinum point. This is accomplished practically by using a zinc cup.

The barretter and its various modifications form a class of detector that is very satisfactory. It is sturdy, despite its almost microscopic dimensions; it can be operated when mounted on a rolling ship, or when the table on which it is supported is moved suddenly or even dropped a distance of a foot or so. In the event of breaking the small platinum wire at the point of immersion, it is a matter of a moment to screw down more of the wire and thus form a new point. The cell operates best when a pressure of approximately 1.6 volts is impressed across it.

The small point should preferably be connected to the anode, as it is somewhat more sensitive with that arrangement, though it is operative with either connection. The current changes are of the order of 1×10^{-6} amperes, but this is ample for a telephone, though too small to operate a relay with certainty.

This detector, like the hot-wire detector, recovers very rapidly and consequently enables one to distinguish between each of several sending stations.

A paper presented at a Meeting of the Pittsburg Branch of the American Institute of Electrical Engineers, April 10, 1906.

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ELECTRIC POWER TRANSMISSION.

BY FREDERICK DARLINGTON.

Electrical power transmission has given a great impetus to the development of water powers, and an understanding of these powers has become one of the duties of electrical engineers. There is a great variation in hydraulic plants in the characteristics that determine their usefulness; and these variations are the result of natural conditions and the manner of development.

The value of a water power is the resultant of two sets of factors; the size and natural opportunities of the water power, and the extent and nearness of the market for power. The market has been greatly broadened by the growth of electrical transmission, and the useful and profitable application of water powers to business uses offers some very interesting problems. The following is a classification of water powers according to the qualities that chiefly affect their value:

1. *Powers capable of continuous operation at their full capacity at all seasons.*—There are comparatively few belonging to this division; they are mostly developments on large rivers or on the outlets of large lakes, where the flow of water is so abundant or is so equalized that water shortage does not occur.

2. *Powers capable of continuous full operation only a part of each year, except in seasons when the flow of water does not reach its minimum.*

There are two natural subdivisions of this class of power:

a. Powers that are capable of being operated to their full capacity a portion of each day, even when the flow of water is insufficient to maintain full power for a full day.

b. Powers that owing to natural conditions or plant design are limited by the flow of water so that in dry seasons they cannot develop power to the full capacity of their machinery even for a few hours a day.

By far the majority of developed powers belong to this division, either subdivision *a* or *b*, according as they have, or do not have an available pond from which water, stored at times of light load, can be drawing during heavy loads.

3. *Powers that are occasionally interrupted in whole or in part by conditions other than low water.*

This includes developments with a low head of water on the wheels and a low dam that is "drowned out" during freshets so that the power is interrupted; also powers that are liable to interruption from anchor-ice.

A further division might be made to include powers that are subject to interruptions belonging to two or more of the foregoing divisions. Such developments do not often bear the test of economical usefulness.

There are several classes of loads to which water powers are applied, and for consideration in connection with hydraulic developments they may be divided according to the load-factor.

DIVISION I.—*Twenty four hours per day service or loads having approximately* 100% *load-factor.*

To this division belongs the power supply for a few manufacturing operations mostly of an electrochemical nature and usually conducted on a large scale, also some pumping and blower work.

DIVISION II.—*Ten hours per day loads (week days) or fifty five to sixty six hours per week.*

To this division belongs mill work, such as in textile manufacturing concerns and a great variety of factories.

DIVISION III.—*Ordinary mixed commercial loads, such as lighting and electric railway and sundry services.*

This division includes a great variety of work, and the daily station load-factor may be the resultant of many small loads and is often vastly different in summer and winter.

DIVISION IV.—*Loads that can be occasionally discontinued without serious loss.*

There is not much power business of this kind.

The cost to a hydraulic plant of carrying a load depends on the plant and the nature of the load. Curves showing the cost of power may be drawn for any plant if the characteristics of the plant are fully known.

Water-power plants belonging to the first division enumerated will produce 24-hour per day power almost as cheaply as 10-hour per day power, while to some plants 10-hour per day first-class power costs about half as much as 24-hour per day service.

The following are some of the general conditions, both as regards natural opportunity and the limits set by their design, that should determine the extent and manner of most water power developments.

PRELIMINARY DATA FOR HYDRAULIC DEVELOPMENTS.

Determinations must be made of:

1. The minimum flow of water, together with the probable duration of low-water periods.
2. The available head at the wheels.
3. The maximum flow of water and the effect of floods in reducing the working head.
4. The pondage or storage that can be obtained and utilized.
5. The effect of ice, especially anchor ice, and so-called "frazil" ice.

The first duty of a hydraulic engineer in preparing a plant design is to determine these points, after which he can do much to shape the development to meet the requirements of the loads to be carried.

The predetermination of water-flow is seldom capable of exactness, except were water-powers have long been established, or gaugings made over a period of years by Government observers.

The flow of a river is usually estimated on the basis of the cubic feet per second per square mile of watershed and depends on:

a. The condition of the country, wooded or cleared.

b. The rainfall.

c. The character and shape of the ground and the nature of the underlying strata.

d. The latitude and elevation above sea-level which affect evaporation.

e. The character of the river-bed and the lakes, if any, included in the watershed.

f. The effect of winds in changing the water-level at the outlet of lakes that discharge into the river.

g. The effect of other water powers in the river holding back water during certain hours.

The following table gives the minimum flow in cubic feet per second per square mile of watershed of a few of our well-known rivers:

Housatonic River,. .0.25 to 0.33 cubic feet per second.
Susquehanna " 0.08 to 0.09 cubic feet per second.
Hudson " . . . . .0.12 cubic feet per second.
Little Tennessee " . . . . . .0.40 cubic feet per second.

These are approximate extreme minimums. Periods of 10 or 20 years occur frequently in which these extremes are not reached. A reasonable working minimum should be assumed for planning developments. As enumerated above, there are many variables affecting the minimum flow from a water shed. In general, extensive forests are the best natural equalizers of the flow of a river. The maximum discharge must be determined and there are a number of methods of estimating this, but this is neither the time nor the place to consider them. Generally the larger the river drainage area the less the flood discharge per square mile.

The following table gives the maximum flow recorded for a few rivers, together with their watershed areas:

Name of River.	Area of watershed square miles	Max. flow cubic ft. per second per square mile
Raritan River, N. J.	879	59.30
Merrimac River, Lawrence, Mass.	4,600	19.12
Potomac River, Great Falls, Va.	11,476	15.20
Mississippi River, near Arkansas City	1,102,600	1.58

Flood-marks and other records are usually to be found showing the maximum rise of a river at any point. With this knowledge, and surveys of the river channel, the maximum discharge can be approximately calculated.

The head or fall for a water-power development is obtained either by erecting a dam to raise the level of the river, or by building a canal or penstock, or by both. A dam serves the double purpose of raising the level of the river and producing a storage-pond. The storage-pond is often of prime importance. An open canal or flume has the disadvantage that even if used in combination with a dam, the water cannot be drawn from the dam after the level has fallen below the point required to maintain a flow in the flume; also in the event of a rise in the headwaters, the canal will overflow and the level of the water on the wheels will not rise with the river.

In cold countries ice often retards the flow in a flume.

The extent to which a pond can be utilized to control the flow of a river and carry over peak-loads is often limited by whether or not the river will deposit silt and fill up the storage-pond.

Freshet conditions often control the amount of machinery to be installed in plants with low heads of water. At flood times, when a river rises greatly, the rise in the dam or intake to the wheels is seldom as great as in the tailrace or channel below the dam, so that the available head on the wheels is reduced; thus times of maximum water may be times of minimum power.

The following are the details of a certain plant. The power is on a river in the Southern Appalachian Mountains; the watershed area is 945 miles.

A careful estimate determined the minimum flow at the high value of 0. 6 cubic feet per second per square mile, or 567 cubic feet per second. The plan of development is with a dam, producing a large pond that will permit the use of the low-water flow of the river without waste, with a 24-hr. station load-factor of 50%. The pond can be kept sufficiently free from silt to maintain this condition. The available head on the wheels with a full pond is 52 ft., and the average head during low water is estimated at about 50 ft. The river is wide below the dam and there is no open canal so that there will be no great loss of head in floods, and the speed and full power of the wheels can be maintained at such times. 567 cubic feet per second at 50 ft. head will develop 2550 h.p. on the wheel-shafts. This will generate and deliver at the market, after deducting transmission losses, 2070 electrical h. p., 24 hours per day.

The market for power is chiefly cotton mills that run 66 hours per week. The daily load-factor will be about 50%. At this load-factor the plant has a capacity of 4140 electrical h.p. delivered at the market, which is the rating of the plant determined by the low-water flow of the river.

Machinery is installed for 7200 h.p. at the power-house (without a spare unit), this is equivalent to 6360 h.p. at the market, so that there is an excess of 1230 h.p. of second-class power. This latter power will fail in years of drouth for short periods up to two or three months, according to the duration of low water.

Herewith is given an estimated power-cost chart for this plant, based on the following construction and operating costs. The transmission line and step-down transformer costs are not included. The estimated yearly repairs, renewals and depreciations, are given opposite the construction costs:

	Construction cost	Repairs, renewals and depreciation	
		Per cent.	Per year
Dam, tail-face and foundations	$412,000.00	1.%	$4120.00
Racks and gates	16,500.00	8.	1320.00
Power-house above foundations	12,000.00	1.5	180.00
Cave in place	4,000.00	2.	80.00
Board house for attendants	3,000.00	xx	xxx
Electric machinery	101,000.00	6.	6060.00
Wheels and governors	50,000.00	10.	5000.00
	$598,500.00		
Engineer's and general expenses and interest during construction	62,500.00		
Property rights	30,000.00		
Total	$691,000.00		$16,760.00

The annual cost of power from this plant is estimated:

Repairs, renewals and depreciation	$16,760.00
Interest at 6%	41,460.00
Operating plant	15,000.00
Legal, traveling and sundry expenses not included in operating	5,000.00
Taxes	2,000.00
Sinking fund at 1% of cost	6,910.00
Total cost of power per year	$87,130.00

If water was abundant the annual cost would not be materially affected by the daily output, and the cost per electric horse-power year delivered at the market, exclusive of the transmission line cost, and without profit, would be $\left\{\frac{\$87130.00}{6330.00}\right\} = \$13.75$ per electrical horse power per year.

As the minimum flow of the river will deliver only 2070 electrical horse power at the market 24 hours per day, the cost of 24-hr. first-class power will be $42.10 per year $\left\{\frac{\$87130.00}{2070}\right\}$, and 8-hr. per day first class power; that is, power that will not fail in seasons of low water will cost $13.75 per year.

The solid line on the diagram shows the cost per electrical horse power per year at the market of first-class power for the various hours per day as determined by the low-water flow. To apply this diagram to find the cost of power for mill operation, there must be added the yearly cost of transmission, step-down transformers, and motors. These are not included in preparing this diagram.

The dotted line on the same diagram shows the cost of steam power per year per indicated horse power in the cotton mills in the vicinity of the water power, mills with steam-engine plants of 1000 h.p. each.

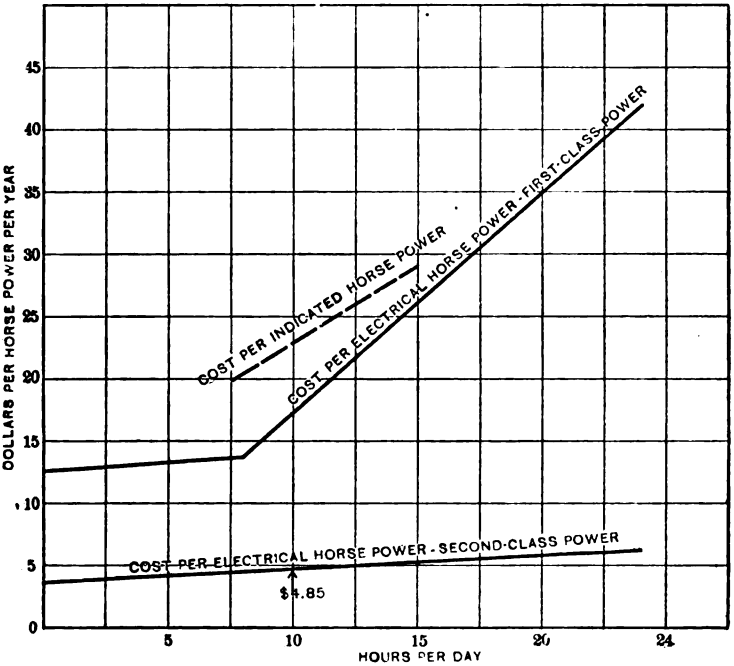

FIG. 1.

Cost of plant ($50.00 per indicated h.p. of capacity	$50,000.00
Annual cost of 1000 indicated h.p. in mills.	
Labor	2,220.00
Coal (2-lb. per indicated h.p.) at $3.25 per ton	12,000.00
Oil waste, and light repairs	1,000.00
Interest at 6%	3,000.00
General expenses	2,000.00
Sinking fund 2%	1,000.00
Repairs, renewals and depreciation	3,000.00
Total cost per year	$24,220.00
Yearly cost per indicated h.p. (66 hours per week)	$24.22

For mill purposes an indicated horse power may fairly be compared to an electrical horse power delivered at the mill.

The upper dotted line on the diagram shows approximately the cost per year per indicated horse power of steam power for various hours per day of service. This cost is made up on the basis of interest and sinking fund and 15% of the coal and one half of the labor and general expenses and repairs, renewals and depreciation, and oil and waste, unaffected by the hours of service and all the remaining items of cost directly proportioned to the hours of service. To meet these conditions, labor released by shortening the hours of engine-run would have to be used in repair work or other work about the mill. These divisions just given can only be considered approximate within reasonable limits, but for the variations shown by the dotted line on the diagram they are approximately correct.

Note that the fixed charges per indicated horse power for the steam plant; that is, the charges that are wholly independent of the hours of use, are about $8.00 per year.

If the steam plant described is installed and held in reserve as an auxiliary to the water power, the total cost of power per year will be the cost of the water powers plus $8.00 per horse power per year, plus the cost of operating the steam plant as an auxiliary.

The cost per electrical horse power per year of secondary power from the hydroelectric plant is shown by the lower dotted line at $4.83, and is determined as follows:

COST OF SECONDARY POWER.

Construction cost per electrical horse power capacity at the market:

	Cost	Repairs, renewals, and depreciation
Dam, etc	00.	xx
Racks and gates at 8%	2.61	0.21
Cave	00.	xx
Power house (1½%)	2.50	0.04
Electric machinery (6%)	15.95	0.96
Wheels and governors (10%)	7.88	0.79
	$28.94	$2.00
Eng. and interest	2.89	
Total	$31.83	$2.00

Secondary power at the market (exclusive of transmission-line cost)

Repairs, renewals and depreciation, per electrical horse power per year	$2.00
Interest, 6% on $31.83	1.91
Operating plant, about	0.50
Taxes. about	0.10
Sinking fund at 1% of cost	0.32
Actual cost of secondary power per year	$4.83

$4.83 per electrical horse power per year for 10 hours per day service is the cost of second-class power to this plant when being operated for first-class power. This power will fail in seasons of low water. In other words, if more machinery were installed it would cost with this plant, $4.83 per year to generate power that would fail in seasons of low water, but would be available from seven to twelve months per year according to the rainy seasons. If the secondary power were used more or less than 10 hours per day, there would be a slight increase or decrease in the cost due to the change of wear on the machinery—the cost of secondary power on the diagram.

The diagram is useful only to show the relative cost of steam power and power by the hydroelectric plant described when employed in mill work. To apply to electric lighting and railway and sundry work, an entirely new and much more complicated diagram must be drawn.

For the steam-driven plant, it must include the interest, depreciation and repairs on the electrical machinery; the losses in conversion of the mechanical power of the engine into electrical power must be accounted for; and the wages of an extra shift of men must be added to the steam-power cost.

As a partial offset to these items would be this advantage of the steam-plant, that at a reduced economy it would carry for short periods large overloads, which would care for peaks that occur in lighting and railway work. Water powers rarely have capacity for overloads much in excess of their rating.

Electrical transmission has made it possible for water powers to reach and serve a widely-diversified market, and in developing them to meet the present conditions many interesting engineering and economic problems arise. Every case must be analyzed and each of the matters suggested herein should have careful consideration. Every manager of a hydraulic plant should fully understand the characteristics of his property and carefully consider the demand on his plan of each item of load added to his system. There is no power load that will not pay at some price, but profit or loss is the resultant of many variables both in the plant and in the load. The best results can only be obtained by a full knowledge and understanding of these, and good judgment to select and combine the most advantageous loads reached by the transmission system.

DISCUSSION ON "TRANSFORMATION OF ELECTRIC POWER INTO LIGHT," AND "NEW TYPES OF INCANDESCENT LAMPS," NEW YORK, NOVEMBER 23, 1906.

Herschel C. Parker: The problem of the transformation of electric power into light is of equal importance to the physicist and to the electrical engineer. When an electrical engineer experiments on the problem, he is experimenting in the domain of physics; when a physicist works on the problem, he is an electrical engineer, if his experiments are successful; if not, he is simply a physicist. There are only two or three points in Dr. Steinmetz's beautiful paper on which I am capable of saying anything that will interest you. The first is the fact that it is not the melting point of refractory substances that gives a high efficiency, but it is the point of disintegration or vaporization, shown by the tungsten filament and tantalum filaments which have a much lower melting point than carbon, but are much more difficult of vaporization, and hence show a great increase in efficiency. Mr. Walter G. Clark and I have been experimenting for a number of years on the subject of incandescent lighting, and we hope in the near future to present before the Institute some of these results which we think are of interest. A certain filament with which we have been experimenting, one substance of which is supposed to have a melting point of about 1400° cent., has shown an efficiency in experimental lamps of about one watt per candle, with an average life of 700 to 1200 hours. The vapor-tension of this substance is remarkably low; that is, it is almost impossible to vaporize the substance. This bears out in a remarkable manner the statement of Dr. Steinmetz. Another point about this filament is that if at the low temperature of 1800° or 1900° cent., it will give an efficiency of one watt per candle, we certainly must believe that some substances have a considerable selective radiation in the solid form, notwithstanding what the experiments of Messrs. Waidner and Burgess have shown regarding the tungsten and tantalum filaments.

Dr. Steinmetz's remarks about vapors, that we have the most intense selective radiation without respect to temperature, is shown in a wonderful manner by the experiments in connection with the electrodeless discharge. Mr. C. C. Trowbridge has carried on some very elaborate experiments in this field at Columbia University, and has shown that when the receiver is surrounded by liquid air a very considerable luminescence can be obtained and be continued for a number of minutes after the electrical disturbance has been discontinued. His calculations show that if the number of molecules in the rarified gases could be increased, and the same effect obtained, the efficiency would be enormous, approximating 100 per cent.; that is, we can have luminescence in the gas that is absolutely independent of temperature.

Concerning arc lamps and their efficiency. I am glad to get some little idea of what the efficiency of these flaming arcs really is. If the efficiency is one-quarter watt per candle and the efficiency of the incandescent lamp is one watt per candle, since we have a superior means of distribution with the latter and the illumination is in terms of the normal daylight spectrum, the absolute illuminating value would not be far behind the arc lamp at one-quarter watt per candle; but experiments we have been carrying on indicate that it may be possible to reach an efficiency approximating one-half watt per candle, and that in terms of the normal daylight spectrum. There would then be no question that with such a high illuminating value the incandescent lamp would be fully equal, if not superior, to any form of arc lamp known at the present time.

John W. Howell: Practically all of the efficient illuminants mentioned to-night originated abroad. We have the Welsbach mantle, which marked a great advance in the efficiency of gas lighting, the osmium lamp, the tantalum lamp, the Nernst lamp, the tungsten lamp, the flaming arc—all originating either in Germany or in Austria.

Dr. Sharp presents a table in which it is shown that the carbon filament, from 1888 to 1904, sixteen years, improved 2.5 times in value in life at the same efficiency. He also shows a curve which indicates that the tungsten lamp is at least 300 times as long lived at the same efficiency as the carbon lamp, even after its sixteen years of improvement. It is hard to realize what that means. It means, as both the papers have stated, a revolution in the art of incandescent lighting, and of all lighting. This tungsten filament, from the nature of the material, can be most easily made in rather large candle-powers. Dr. Sharp puts 25 c-p. as the lower limit, but the really practicable lower limit is higher than that. I think that 40 c-p. would be about the lower limit at 110 volts; for lower candle-powers, lower voltage lamps will have to be employed either in series or in other ways. But while that is the limit, it fits exactly in the place where the carbon filament is weak. Above 40 c-p. the carbon filament is weak and the tungsten filament is strong. The tungsten filament from 40 to 200 c-p. is at its best. At these candle-powers, the incandescent lamp, with its distribution and stability, is better than twice that candle-power in an arc lamp; and I look to the tungsten lamp as a probable competitor of arc lamps, and for other forms of light, the values of which lie between 50 and 200 c-p.

These curves shown in Fig. 14 were made at the Reichsanstalt.

The lamps were sent there on the 25th day of April, 1906, but before that time another set of these same lamps had been burning at the Reichsanstalt. I saw the records of these other lamps, and got a copy of them. They were set up at 1.3 watts per heffner, and burned 700 hours, and at the end of the time each one of the lamps was higher in candle-power and of better efficiency than when it started. That is probably the first recorded test on 110-volt tungsten lamps. The high temperature of the tungsten lamp is of course a large element in its efficiency. The selective radiation is described by Messrs. Waidner and Burgess, and it is shown that the quality of the radiating surface has also a great deal to do with it. The carbon lamp is a much better radiator of heat than a metallic filament. The more polished the metallic filament the worse radiator it is, and the more slowly it radiates its energy at a given temperature the more slowly energy has to be supplied to it to maintain the temperature. As Messrs. Waidner and Burgess state, a polished platinum wire is the most efficient metallic light-giving body. Some of the tungsten filaments approach very closely in appearance to polished platinum wire, and I think those forms will be more efficient than the others which do not approach that condition.

Percy H. Thomas: Dr. Steinmetz gathers together and summarizes the latest information as to the general nature and the best performance of the various kinds of devices for getting light from electric power. Dr. Sharp has certainly brought us up to date on the subject of incandescent lamps.

As I understand Dr. Steinmetz, he attributes the superior efficiency of gases as a source of light to the fact that their radiations are, relatively speaking, largely in the visible spectrum. This is undoubtedly true. A more satisfactory idea of the distinction between solids and gases as to their light-giving characteristics, can be gotten by considering the corpuscle theory of electricity in its relation to the emission of electric radiations by hot bodies. By many scientists light is assumed to consist of electromagnetic waves produced by vibrations within the atom, or by vibrations of the body of the atom itself. In this view the atom may be said to send out light waves when agitated, in the same way that a bell sends out sounds when struck with a hammer. As these sounds are of one pitch, or of a few related tones, so are the colors of light given by an atom of gas of one color or a comparatively few related colors. In an incandescent solid, light rays are still given out by the atoms themselves, but these atoms are so crowded by other atoms that they cannot vibrate in their natural period and all colors of light result. Furthermore, a great deal of energy is given off in heat radiations which are due to the translatory motion of the atoms and molecules backward and forward. Evidently, the natural time-period of vibrating molecules will be much lower than that of the vibrations within the atom, the former corresponding to the longer heat waves. As Dr. Steinmetz has said, these heat waves are a necessary waste of energy in the production of light.

Returning now to the emission of light by molecules of a gas; as, for example, in a Cooper Hewitt lamp. Here we have a number of presumably isolated vibrating atoms, and a series of projected corpuscles representing the current and passing from the negative to the positive electrode at very high velocities. These corpuscles must frequently strike atoms, and in so doing cause both the deformation or bell-like action and also a translatory motion. But, since they are of extremely small mass and high velocity, they will produce a large percentage of vibration and a small percentage of translation corresponding to an efficient production of light. This hypothesis tends to confirm an observed fact; namely, that those gases or vapors having relatively large atomic weight are more efficient sources of light when excited by electric current. For in such cases the relative amount of translation in relation to the internal vibration for the relatively heavy atom will be less than for the relatively light atom. Dr. Steinmetz has linked the efficiency of light sources with the boiling point of the materials giving a light. In some ways it appears to me more likely that differences in atomic weight rather than differences in boiling points determine the efficiencies.

Another point of a very much more practical nature is worth considering. We have covered pretty well the theoretical considerations governing the absolute, or what you might call the physical efficiency of the different methods of producing light. This physical efficiency is very important, but must be considered in connection with other practical considerations before it is applied in actual cases; that is, there are other things besides the physical efficiency which determine the usefulness of a lamp. For example, there must be inherently in such lamps as arc lamps, where the air and other gases are in contact with the hot bodies, a convection loss of heat, allowed for only incidentally by Dr. Steinmetz, and which may be of material importance. This fact will tend to decrease the advantage of the arc lamp over the incandescent lamp.

The size of units is of very great importance. This point has already been raised. A source of light which has for its smallest practical unit two or three thousand candle-power, like some of the flaming arcs, cannot get the advantage of its high efficiency because so much light at one point cannot be used economically. The contrast between the locations of a superabundance of light and locations more remote from a lamp with little light, interferes materially with the effectiveness of even that value of illumination which does exist in the darker portions.

High intrinsic brilliancy in a light source is harmful, in that it causes a contraction of the pupil of the eye even when the light is not directly in line of vision, so that comparatively ineffective use is made of the available illumination. This is a matter of the very greatest importance which has not until recently been fully realized. The arc light, especially the open-air arc light, the flaming arcs, and the bright incandescents suffer from this cause. Evidently the tube lights, such as the Moore tube and the Cooper Hewitt lamp have a great advantage over the other types in this regard, and furthermore cause no sharp shadows.

Greatly to the advantage of the Cooper Hewitt lamp, as Dr. Steinmetz points out, the colors of light most easily and naturally utilized by the eye are those in the middle portion of the visible spectrum, the yellows and greens. The Cooper Hewitt lamp is the only electric light having a majority of its light of these colors.

Walter G. Clark: In paying my respects to Dr. Steinmetz's most excellent paper, I wish to state that in connection with the experiments which are being conducted by Professor Parker and myself, I have had an opportunity to note the behavior of carbon filaments, and it has been my impression for some time, that the vaporization of carbon from the carbon filament is far in excess of that warranted by the temperature of the filament. Carbon maintained at a high temperature by an external source of heat, but within a quartz receptacle, did not show the vaporization that it did at a much lower temperature when the heat was produced by passing a current through it.

A number of experiments of this character together with the study of the filaments themselves have led me to believe that the ordinary filament is not of even temperature, but is made up of very narrow zones or spots of high incandescence and possibly, in an unflashed filament, of actual arcing in some places. The temperature which we observe most likely is the mean of a series of high-temperature and low-temperature spots, these would of necessity be very narrow; but from the fact that the filament is originally made up from a material which must pass off as a gas during the process of carbonizing, it must leave the filament somewhat porous. As the surface is carbonized before the interior, the gases leaving the interior would break through any surface-seal formed by the carbonizing of the surface and reduce the cross-section of the filament at that point; in an unflashed filament there would be a tendency to form a small arc across the gap in shunt with the continuous portion of the filament back of it. In flashing, these spots would be the first to be covered with the dense low-resistance carbon deposited out of the hydrocarbon, and as the temperature is excessively high at this point and the carbon deposited is of very low resistance, compared with the porous unflashed portion, the tendency is to over-deposit; for the carbon is not only deposited at the actual point of the greatest temperature, but for some distance on either side, so that while flashing improves the filament it does not entirely eliminate the high-and-low temperature conditions. But the temperature of a carbon filament probably represents the mean of a great number of extremes of high-temperature and low-temperature zones, and the carbon is vaporized from the high temperature points at an increasing rate until the filament parts.

With the graphitized or metalized filament, the conductivity is more nearly uniform on account of the greater per cent. of dense carbon, so it is possible to operate the filament at a higher temperature. ·I am of the opinion that the hot-point conditions also hold where metallic filaments are made up of colloidal tungsten particles, for the current passing through the filament at the time of the entering together will follow the path of lowest resistance where the arcing between the particles welds them together; and particles not directly in the path of the current may not become an active part of the filament. The arcing between the particles would continue until the points of contact fused together, when the temperature would immediately drop below the fusing point, but the points of contact would still represent the points of greatest temperature. On account of the fineness of the particles in the Kuzel filament, these zones of maximum and minimum temperature would be very close together. This condition may account for the higher resistance and high temperature coefficient of this type of filament.

It has been noted that some metallic filaments which are white in color at low temperature still radiate as black bodies. I have noted in some experiments that some white metals turn black before they begin to radiate light. Steel of a light gray or silvery color and confined in a vacuum, passed through several changes of color to black before it began to radiate light at the red end of the spectrum; this was also true of platinum, iridium, and copper, but did not appear to be true of aluminum. I was careful to remove the oxide from the surface of the aluminum and place it in a receiver filled with hydrogen, which I pumped out to create the vacuum, still a film of oxide may have formed which concealed the color-change; but experiments with thorium oxide, oxide of aluminum, flocculent silicon dioxide, calcium oxide, and a number of other white oxides or white-oxide forming materials indicated that they luminesce or become incandescent direct from their own white color to the characteristic light or wave-lengths which they emit without passing through all of the longer wave lengths leading up to and through the red end of the spectrum. I have also noted that it is possible to make a non-luminous gas flame luminous by charging it with a silicon vapor which broke up and gave silicon dioxide upon coming in contact with the air. I have found it difficult to prevent the oxidization of silicon when in contact with air at high temperatures. I do not understand the statement that the silicon arc is non-luminous, assuming that Dr. Steinmetz is referring to an open arc. The oxidization of carbon in the arc would, of course, produce a gas which would show little if any luminosity, but the oxidization of silicon produces dioxide and in my experience becomes luminous at a comparatively low temperature, and an open arc from silicon should form the dioxide and become luminous.

The desirability of obtaining a light which covers the entire range of visible wave-length is brought out very well in this paper, but instead of endeavoring to obtain this entire range in one material or in two similar materials, as in the magnetite-titanium arc, may we not secure an efficient result by combining materials which show high efficiency at each end of the visible spectrum? For instance, if we were able to combine the mercury vapor arc with a light from a material which showed its highest efficiency in the red end of the spectrum, the resultant light should be both satisfactory and economical. The carbon filament is, of course, not sufficiently efficient when maintained at a temperature where the red rays predominate, but a combination of the Geissler tube effect with the mercury vapor arc would be a step in this direction.

The matter of selective radiation is now just being raked over, and I expect to see some marked improvements in the near future in the matter of improving the efficiency of electric lighting along the lines of selective radiation rather than from high temperature of materials showing low vapor-tension.

C. W. Hogan: Some time ago my attention was called to a new form of carbon filament, in which an efficiency of 2.5 watts per candle-power was claimed, with an increased life over our present form. I was afterward told that this was due to the cross-section of the filament, and I then made some calculations concerning the difference between the triangular and the circular cross-section. The triangular filament of 5 mils per side is compared with the circular filament having a diameter of 5 mils. In the triangular filament the section is 10,825, and in the circular, 19.66 sq. mils. With the same radiation surface it will give a length of 9.8 for the triangular, and 9.33 for the circular filament. With the same specific resistance, it will give resistance of one inch of carbon, for triangular 147.8, and for circular, 81.4 ohms. The final efficiency figured for 16 c-p., using the same method of treatment for the same carbon material, would be 1.74 watts per candle-power for the triangular section against 3.31 for the circular section.

I should like to know if there is anything in the nature of the carbon which would render these figures void; that is, if the current density will be as uniform throughout the triangular cross-section as it is in the circular cross-section. The amperes for that efficiency would be in the triangular cross-section 0.253 and for the circular section 0.482, so that the carbon would actually be carrying less current in the triangular section than in the circular section. Consequently, it would be at a lower temperature, and having a greater radiating surface the life would be longer owing to the lower temperatures at which the carbon would be operated. And the total illumination from the triangular section would be greater, as there would be more radiating surface for the light.

Charles P. Steinmetz: Answering first the questions raised during the discussion: I observed the tarnishing of iron in a vacuum, also when trying to use iron in the mercury arc lamp. Even in a very high vacuum, iron when heated shows the rainbow colors. I found, however, that even in a very high vacuum, if the mercury arc was started and the space so heated from the inside, remarkably large quantities of gas were given off by the glass walls, etc., and to get a reasonably perfect vacuum it is necessary not only to get a very high grade mercury pump, to have only solid glass connections between the mercury pump and the vacuum tube, but to heat the tube by a heating chamber to a temperature just below where the glass sucks in and keep it at that temperature for hours with the pump working. Then you get a good vacuum, usually, but not always. I consider it possible, therefore, that residual gas, absorbed and tenaciously held by the glass walls, may gradually be given off and affect the iron or other metal.

As to the non-luminous silicon arc, and the production of a very brilliant gas flame by silicon distributed through it, this is a question of comparison. The intrinsic brilliancy of a gas flame is so very low compared with that of a luminous arc, that incandescent silica in the gas flame may appear very brilliant compared with an ordinary gas flame, while compared with a titanium or calcium arc flame, it would have to be called non-luminous.

In regard to 3200° cent. as the melting point of tungsten: 3200° cent. is the black-body temperature of melting tungsten, that is, the temperature which melting tungsten would have if its radiation were that of a black body, but if, as it is very probable, the radiation of tungsten is not that of a black body, the true temperature of the melting point is lower than 3200° cent.

The manufacture of tungsten lamps would possibly be simplified if the metal could be made ductile. I must draw your attention to one feature, however: of all the incandescent filaments, the only one not suited for alternating current is the ductile tantalum filament, which shows a feature similar to the crystallization of wrought iron under rapidly oscillating stress, while the osmium and carbon filaments, which have no fibrous structure, show no inferiority with alternating current. It appears to me possible, therefore, that a ductile tungsten filament may be unsuitable for alternating current.

It is undoubtedly true that the increased surface of the triangular section radiates more light. Unfortunately, it also radiates in the same proportion more heat rays and more total radiation; that means the efficiency would be no better than in the case of the round filament, and the only difference would be that the total radiation from a triangular filament would be greater than the total radiation from a round filament of the same section, and therefore to maintain in the same temperature of the triangular filament would require more energy input. The same would be the case by using a hollow filament, but no gain in efficiency results.

Like many other interesting things, the fluorescent cathode-ray lamp has been tried in by gone years by Edison; an exhausted glass tube, coated on the inside with calcium tungstate crystals gave a beautiful white glow. I saw it in operation, but I understand that the difficulty was that the luminescence excited by the cathode rays is excited by an extremely high velocity bombardment, and the impact of this extremely high velocity does not only give light, but gives mechanical fracture and destruction of the fluorescent crystals, and so limits the life of the lamp.

As to the discussion of the various illuminants. We are living in a remarkable time. A few years ago we had the incandescent lamp which as commonly used for series lighting of streets etc., looked somewhat like a red-hot hairpin, which you could see to steer by, just like a beacon light on the river; you could see the light, but you could not see anything with the light. There also was the arc lamp: a big blotch of light, when you were under it you did not see anything, but were blinded by it, and before you came under it you could not see beyond it, and after you left the light you could not see anything at all.

The incandescent lamp has now been redeemed. It promises an efficiency of one watt per candle-power. That means it is superior to the ordinary carbon arc lamp; and possibly you may go still higher in efficiency: the maximum efficiency of light given by a tungsten filament at the temperature of self-destruction is something like 0.2 watt per c. p.; that is, if you run a tungsten lamp up, voltage the efficiency rises to something like 0.2 of one watt per c-p. at the moment where the filaments melt; that is, the efficiency at the melting point of tungsten. This efficiency has been beaten by the flame carbon arc lamps and by the different types of titanium arcs. At the same time, the arc is a larger size illuminant. The incandescent lamp has the advantage of giving better distribution of light by smaller units; but the tungsten filament does not have this advantage as much as the carbon filament, because at least at the voltage of 110, it cannot be brought down to the same small units as can the carbon incandescent lamp. This means that very high efficiencies, undreamed of a few years ago have been reached, and the race is still on between the arc and the incandescent lamp. There are future developments possible also in increasing the efficiency of the arc lamp, because even an efficiency of ¼ of a watt per c-p. is ridiculously low compared with the efficiency of the electric motor. However, what is wanted is not light, but illumination, and in the problem of illumination the distribution of light is of importance also, besides the total volume of light. In this respect the smaller size of units gives an advantage to the incandescent lamp. Again, high intrinsic brilliancy is a disadvantage; and low intrinsic brilliancy, that is, large light giving a surface, preferable. In that respect the advantage is with the mercury arc and the vacuum tube and against the ordinary arc, and also against the high efficiency incandescent lamp.

Furthermore, the specific physiological effects of the different colors of light also enter as essential factors, and this is a feature which never had to be considered before, because until the last few years all artificial illuminants gave about the same color, varying from an orange-red to yellow and yellowish-white, while at present you have the bluish-green of the mercury arc, the monochromatic yellow of the calcium spectrum, the white of the titanium arc and so get different colors of light, and the difference of the physiological effect of different colors thus requires consideration.

I stated in my paper, for instance, that green is a much more efficient color than red, and that the same amount of energy as green light gives many more candle-power than as red light; that is, the light-equivalent of energy is a function of the color. It is, however, not only a function of the color, but also a function of the total intensity. The relative sensitiveness of the eye for lights of different colors varies with the absolute value of the illumination. The difference of the sensitiveness of the eye for red light and for green light is many times greater at very low than at high intensity of light. Or, in other words, the physiological effect of lights of different color does not seem to follow the law of inverse squares of the distance, but varies faster than the square of the distance with red, slower with green light. That is, if for instance you have a yellow flame carbon arc and a green mercury arc, which at 100 feet distance gives about the same illumination; that is, appear to the eye as of the same intensity, than at ten feet distance from the light, the yellow light appears far more intense, is glaring, while you are disappointed in the green light. Again, at 1,000 feet distance, the green light appears far brighter than the yellow, and gains over the yellow; the farther away you go from the light, and when the orange yellow light has faded away as a faint star, the green light still throws its visible beam across the darkness. Therefore, where a low intrinsic brilliancy is desired, as in suburban lighting, where the green, irrespective of the physical efficiency, has a great advantage over the reddish-yellow. The reverse applies where very high intensity is desired, a glare of light to draw attention for advertising purposes. Then the reddish yellow is always preferred. These physiological effects of different colors did not receive consideration in former times, but well deserve careful study now, where efficient illuminants of such widely different colors are available, as the flame carbon and the mercury arc.

SELECTIVE RADIATION

William S. Franklin (by letter): When a given substance is in thermal equilibrium at a given temperature, and surrounded on all sides by substances also in thermal equilibrium and at the same temperature, then the radiation from the given substance is what we call the normal or black-body radiation corresponding to that temperature and the composition of this radiation; that is, the relative intensities of its various wave-length components, is a function of the temperature only and independent of the nature of the given substance. The radiation consists, however, of three parts; namely,

a. The part which is reflected by the substance,

b. The part which is transmitted by the substance from behind,

c. The part emitted by the substance.

If the given substance were opaque and if it did not reflect, it would be called an ideal black body and it would emit normal radiation; and if it were heated to a given temperature in the open it would continue to emit the normal radiation corresponding to that temperature, on the assumption that its molecular condition remains still the same as that which constitutes complete thermal equilibrium.

If the given substance transmits or reflects certain wave-lengths in excess of others then it must, when it is in thermal equilibrium, emit certain other wave-lengths in excess (since the total radiation must be normal when the substance is surrounded by substances at the same temperature), and it is said to exhibit selective emission or selective radiation as it is usually called. Such a substance, when heated to a given temperature in the open, would emit a characteristic abnormal radiation on the assumption that its condition remains still the same as that which constitutes complete thermal equilibrium.

Thus, in brief, we have a sketch of the fundamental idea of selective radiation in the form in which this idea is established in the thermodynamic treatment of radiation.

My remarks on Mr. Steinmetz's paper were intended to point out the fact that the idea of selective radiation, as this term is used by Mr. Steinmetz and by every other writer on radiation so far as I know, contains an idea which is entirely foreign to and incompatible with the narrow thermodynamic idea of selective radiation which is outlined above, and that this foreign idea is of extreme importance in the problem of the production of light.

SELECTIVE EXCITATION

Nearly every one knows that a serious inconsistency has for a long time confronted the physicist in the kinetic theory of gases, in that each of the various modes of molecular motion does not represent the same amount of energy, whereas each possible mode of molecular motion should represent the same amount of energy according to the kinetic theory.

This difficulty has quite recently been explained by Professor Jeans, now of Princeton University, on the hypothesis that it takes time, and in some cases a very long time, for energy which is imparted to a gas as a particular mode of motion to become properly partitioned among all of the possible modes or, if a particular mode is very prone to produce ether waves, and thus lose its energy rapidly, its energy may fall far below normal on account of the slowness with which the store of energy of the other modes is shared by the particular mode as it loses energy by radiation.

Thus in a gas the energy of intra-molecular motion seems in certain cases to radiate rapidly, and in a radiating gas the intra-molecular energy is below par while; on the other hand, a gas which is heated by compression in a closed cylinder has energy imparted to it as increased translational motion and, according to Jeans, it may take a very long time for this translational energy to hammer itself, as it were, into the molecule by repeated collisions.

The indications are that the rapidity with which the energy of a particular mode of motion spreads among the various possible modes in any substance, solid, liquid, or gaseous, is a function of the temperature (if I may use the word temperature in a slightly inaccurate way), and that the spreading is rapid at high temperatures and slow at low temperatures.

To show the application of Jean's idea to radiation, let us consider a hypothetical case, a substance to which energy is imparted predominantly in those modes which correspond to luminous radiation, or in those modes which quickly share their energy with the luminous modes. In such a case the radiation from the substance would be predominantly luminous radiation if the spreading of energy into the non-luminous modes is not too rapid, that is, if the temperature is not too high; whereas if the spreading of the energy among the various modes is accelerated by rise of temperature the radiation would tend to include more and more of all the characteristic wave-lengths of the substance. If the spreading of energy were infinitely rapid, the substance would be in a condition approaching the state of thermal equilibrium, and its radiation would be called its selective radiation in the proper restricted sense of this term.

It seems to me that the giving of energy to a substance predominantly in the form of certain modes of motion might be called selective excitation

I wish in particular to emphasize the clear insight which Jeans' idea, as applied to radiation, gives to several remarkable facts which Mr. Steinmetz points out. The mercury-arc spectrum for example contains no red lines of appreciable intensity when the vapor in the arc is relatively cool, whereas the spectrum becomes greatly strengthened in the red and perhaps also in the infra-red if the vapor is very hot; the energy imparted to the vapor selectively by the (presumably) highly particularized mode of motion which constitutes current conduction, is spread rapidly among the various modes when the arc is hot, and only a small portion of it is radiated in the original modes. The slowness of spreading of energy among the modes of motion, even of solid and liquid substances, is shown by the phenomena of fluorescence, phosphorescence, and luminescence of solids and liquids, and also, I think, by the fact that many substances when bombarded by cathode rays emit line or band-spectra. Furthermore the remarkable band-spectra of absorption of didymium salts seem to show a slow spreading of energy into or out of the didimium atom.

The great retardation of the spreading of energy at very low temperature is shown by the fluorescence at liquid-air temperatures of many substances which do not fluoresce at ordinary temperatures.

I agree completely with Mr. Steinmetz in his statement that theoretically there is no limit to the light efficiency of a luminescent vapor, only I would go further and say that there is no limit to the light efficiency of a luminescent substance of any kind solid, liquid, or gaseous, and I would also be inclined to define the term luminescence as radiation under selective excitation.

The reason that there is no limit to the light efficiency of radiation of a substance under selective excitation, is that mechanical energy (as opposed to heat energy) may conceivably be delivered to a substance in a single mode of motion, whereas heat energy cannot conceivably be delivered to a substance in a single mode. Thus an example is given above of the delivery of energy (mechanical) to a gas as increased translational energy only, in the case of compression of a gas in a cylinder, and such mechanical energy of course spreads out more or less rapidly among all possible modes, and eventually becomes heat energy. It is quite remarkable, however, that energy imparted to a gas by compression seems to spread out with extreme rapidity among such modes as play a part in the determination of the specific heat of the gas (as shown by the close correspondence between the calculated ratio of the specific heats at constant volume and at constant pressure of a biatomic gas, and the ratio as determined by methods involving quick expansion such as the method of Clement and Desormes), while the energy is spread into the other modes with excessive slowness.

I believe that the idea of Jeans is destined to play an important role in the theory of radiation from substances not in thermal equilibrium—which indeed is the only actual existent case of radiation.

Consider the Welsbach mantle for example. We know that its spectrum is abnormal; that is, it departs very widely from ideal black-body radiation. Is it likely that this abnormal radiation is a genuine case of selective radiation in the restricted sense of that term, that is to say, is it likely that the hot substance of the mantle presents all of its possible modes of molecular motion in approximately the relative intensities which correspond to thermal equilibrium and that the abnormal radiation is due to a natural preponderance in this substance of certain modes which jar the ether so as to produce luminous radiations, or is it likely that the abnormal radiation is due to selective excitation and a consequent wide departure of the hot substance from the condition of thermal equilibrium? It is impossible to say.

Energy is of course imparted to the mantle by the highly disordered movements of combustion, but surely these movements must be very far removed from the type of molecular motion which constitutes thermal equilibrium. That is to say, the possibilty exists of a marked degree of selective excitation of the substance of the mantle and it seems to me that there is too much of a tendency to think of the abnormal radiation of the Welsbach mantle as an inherent property of the mantle (abnormal radiation due to selective radiation proper is due to an inherent property of a substance; abnormal radiation due to selective excitation depends of course to some extent upon inherent properties of a substance, but also it depends quite as much upon the character of the selective excitation) whereas it may be a mutual property of the mantle material and the particular kind of combustion which is employed to heat the mantle.

Consider the ordinary glow-lamp. Here we have unlimited possibility of selective excitation because the motion which constitutes the electric current is probably a highly particularized mode of motion. The approximately normal radiation from a glow-lamp seems to show an extreme rapidity of spreading of energy among the various modes of the solid substance of the filament.

In the case of a vapor-lamp we have perhaps something like the same kind of excitation as in a solid-filament lamp, but a very much slower spreading of energy, especially if the vapor is relatively cool, and as a result we have an extremely abnormal radiation.

In the firefly, or indeed in slowly burning phosphorus, we most certainly have a strongly marked case of selective excitation coupled with a comparatively slow spreading of energy.

DISCUSSION ON "WIRELESS TELEGRAPHY" AT THE PHILADELPHIA BRANCH, November 12, 1906.

C. D. Ehret: Will Dr. De Forest please state the difference in principle and action between this audion and the Fleming rectifier, whose structural circuits so closely resemble those which he has placed on the blackboard

Lee De Forest: In the first place, Fleming took the old type of tube (see Fig. 1) which was produced in 1882, and which Elster and Geitel had found would rectify currents. Fleming built a cylinder which had been used by Edison, like this:

Fig. 1 shows the positive and negative connections of the battery, with a direct-connected galvanometer, *G*. There is a potential difference between this cylinder and the negative end of the filament in the Fleming rectifier, and, inasmuch as the negative ions are travelling from the hot to the cold body, there is a local current passing through *G* all the time. Thus only the positive half of the current oscillation can pass across the gap, the other half being choked back. By using intense waves and a sensitive galvanometer here, Fleming was able to increase the deflection. The value of such a device as a wireless telegraph receiver is nil. Exceedingly powerful signals are required to affect this galvanometer at all. Put a telephone in the circuit, and if the signals are sufficiently intense you can detect the pulsating currents in the telephone. But it is not practicable, in commercial wireless telegraphy. But now introduce an external electromotive force in the lead to the cylinder and connect the positive terminal with the wing. This increases the positive potential of the plate. The negative of this battery, "*B*," must be connected to the positive of battery "*A*"; then we get the full trigger or relay effect of the hertzian oscillations, which I can briefly call the "variation layer effect," whereby the hertzian

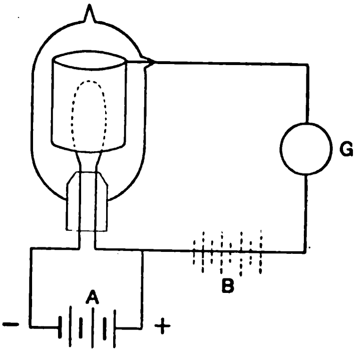

FIG. 1.

pulsations passing across the gap, control the variation layers before the electrode so that the local current flowing all the time has superimposed upon it alternating currents, whose source of energy is the local battery. These pulsations affect the telephone to a marked degree. In Fleming's case we have simply a hertzian-wave motor, and the hertzian wave merely acts with its own energy to cause deflection of the galvanometer armature. In the case of the audion with the two wings, the difference is still more marked, for we have a very marked *decrease* in the local current flow. The hertzian oscillation being applied to this insulated wing, produces now an effect not heretofore described. It causes a decrease in flux, but on top of that is the variation layer effect which I have just described, and which is indicated in the telephone. In a word, the chief difference is this; with the Fleming rectifier we have a hertzian rectifier, and here in the audion we have a relay.

C. D. Ehret: In the audion, is there always a normal flow of current from the battery *B* through the telephone.

Lee De Forest: Yes, always; but superinduced upon this are the alternating currents due, apparently, to the alternating changes in the variation layers.

C. D. Ehret: How do you connect the audion in a tuning circuit. You say it is a potentially operated device.

Lee De Forest: It is connected as shown here in the two-wing type (See Fig. 2). The two wings are connected to one leg of the closed oscillating circuit, or we may have the antenna connected to the insulated wing, and one end of filament connected

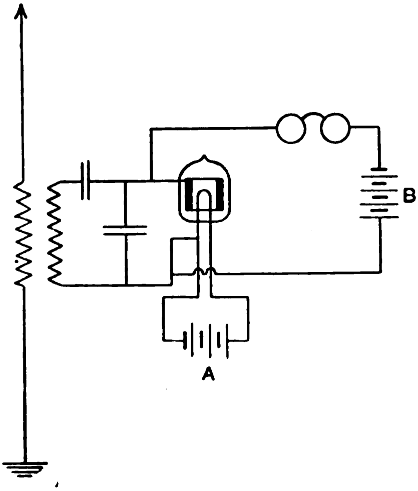

FIG. 2.

direct to earth. It makes a difference in the responses how the audion is connected in the oscillation circuit. If it is connected as shown here, the higher potentials are always applied to the wing, and the lower potential to the filament. The wing should have the maximum potential impressed upon it.

W. E. S. Temple: What is the voltage of the filament.

Lee De Forest: For convenience I use a 6-volt lamp; from 4 to 6 volts, using generally three cells of storage-battery. I started with 110 volts and then decreased it, finding high voltages impracticable, as one hears always a great noise from the dynamo at the power station. The battery "*A*", varies from 4 to 8 volts at the outside, and battery "*B*" from 6 to 18 volts. The current across the gap is very small, and I employ a small set of dry batteries the life of which is at least six months.

H. C. Snook: In connection with the different sensitiveness whch has been noted with reference to the platinum filaments, and the carbon filaments, I would like to ask whether there has been any experimenting done with the tantalum filaments?

Lee De Forest: I am using tantalum filaments entirely; I think they are much better. The temperatures are higher than with either the carbon or the platinum. I have never been able to use the Tungsten filament, but I should think it might give better results than the tantalum.

H. C. Snook: Can you make any statement regarding the use of the alkalis coated on these cathodes, similar to the work done by Dr. Wehnelt of Germany, who states that the saturation of the current with the oxides of the alkalis of earths is much higher than in the case of the elementary metals, or the carbon filaments?

Lee De Forest: The only thing we have done has been to coat them with the alkali salts of potassium and sodium. The life of the filaments is very short, but I presume they may yet be produced so as to be better than the tantalum filament; every consideration points that way.

E. F Northrup: Will you not tell us more about that relay conection. If there is a rapid tap of the key, how rapidly can the relay be made to respond? Because, if you get the relay to act rapidly, you will be able to do a great many things in controlling motion, etc.

Lee De Forest: We have never tried any signals more rapid than those required in the ordinary telegraph practice, about 35 words a minute. Of course the sluggish voltmeter can be seen to deflect even with an instantaneous connection. A relay will operate positively at such speeds with very slight force, and as far as the audion goes, it will at least allow a speed of 35 words a minute, and I presume that with an oscillograph it would reproduce perfectly oscillations of very high frequency. The telephone diaphragm does that.

H. C. Snook: Do you not think that the residue of the gas left within the exhausted envelope has something to do with this lag.

Lee De Forest: Well, of course, the gas has something to do with the phenomenon. If the exhausting process is carried too far, the audion loses its sensitiveness. The gas particles, rather than the particles of the metal dust, are the carriers. I do not believe the dust particles are controlling at all. This extreme lag, when the battery "*B*" is of low voltage, is a most astonishing thing. You cannot imagine the gas all concentrated in that space around the insulated wing, while the hertzian oscillation is passing, but there seems to be either an abstraction of the ions into this space, and a very slow resumption of their original positions, or else a complete de-ionization and a very sluggish reionization. The positive ions and negative ions unite and cease to be carriers; they are then nothing but air molecules. I have never been able to arrive at any adequate explanation for this lag. It is as puzzling as the after-glow in a cathode-ray tube. Here we have the converse effect. Of course the time is seconds instead of hours, but whatever conducting property the gas originally had, is taken away from it for a few seconds, although the forces that gave it that property are still existant.

I would like to know if any one present has ever come across any similar effect connected with the gas particles, or ions, call them what you will?

C. D. Ehret: What is the action of a magnet on this audion. Is it an improvement or a detriment?

Lee De Forest: It is a detriment ordinarily, but it furnishes a way of regulating the flux, which can be regulated in a variety of ways. When the audion is put in a strong field at right angles to the flux of the ions, the ions tend to follow the magnetic lines of force. A great many will then go outside and do not strike the wings at all, so that if you have too great a flux, you can reduce that flux by the magnet and restore the sensitiveness of the audion. As far as I have gone, it seems that the magnetic effect is more pronounced, when receiving low-frequency oscillations than high frequency oscillations, which gives us a new method of tuning.

James Haywood: Can Dr. De Forest tell us what measure of efficiency this instrument has, as compared with former receivers. In other words, how much farther can you transmit a wireless message by using the audion?

Lee De Forest: I wish I could say that the audion is " 865⅔ times " as sensitive as any other receiver, or even eight times, but all I do say is that the audion is more sensitive than the "electrolytic"; the same signals are louder than with the electrolytic, and the operator always prefers the audion because the signals are louder. I wont say you can cover greater distance, but I will say that for practical distances, the signals are louder on the audion than on the electrolytic.

George Breed: Dr. De Forest says that one of these wings should be connected with the high potential side of the converter on the antenna; how does he determine them?

Lee De Forest: One side of the oscillating circuit is connected to the filament and to all the ramifications of the circuits there attached. Here is the 'phone on the operator's head, a virtual ground, and consequently it is important to raise this other point of the oscillating circuit to its highest potentials. This insulated plate can be thus raised. The oscillating current is attuned by varying this shunting capacity and this self inductance, the same as with any receiver, but the tuning is decidedly sharper with the audion than with any other form of receiver that I know of.

A paper presented at the 215th Meeting of the American Institute of Electrical Engineers, New York, March 1, 1907.

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(*Subject to final revision for the Transactions.*)

ALTERNATING-CURRENT ELECTROLYSIS*

BY J. L. R. HAYDEN

A. CONTENTS

The development of the one-phase railway motor leads to the introduction of grounded alternating-current systems, in which the current is returned over the rail. With rail-return, necessarily more or less current strays through the ground, reaching gas and water pipes, lead cables, etc. When using direct current for railroading, lead cables, etc. are protected against electrolytic corrosion by connecting them to the negative terminal of the circuit, so that the stray current enters the cable from the ground, but does not leave it; that is, the cable is always at a negative potential against ground. With alternating currents this method of protection evidently is not feasible, since the potential difference constantly reverses.

An investigation was therefore undertaken to determine whether, and to what extent, alternating currents passing between any metallic conductor and the ground would produce electrolytic corrosion. These tests were started in the spring of 1906, and carried on practically continuously throughout most of the year.

These tests were extended to the investigation of different current-densities and different frequencies. First, several series of tests were made with diluted solutions of such salts as may be expected in the ground. Then different kinds of soils were investigated, and then tests made on a typical soil by adding different substances—carbonates, sulphates, organic matter, etc., and noting their effects. Ultimately, the possibility of protection against electrolytic corrosion was investigated.

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* In arranging this investigation, laying out the tests, and working up their results, and in recording them in the present paper, I am greatly indebted to Dr. Charles P. Steinmetz, in whose laboratory the investigation was made, and to the General Electric Co., which supplied the means and facilities for carrying out the work.

In the first sets of tests, lead and sheet-iron were investigated; in the last tests only lead plates were used, as the first tests proved the relative unimportance of iron.

B. METHOD OF TEST

Plates of 1.25-in. width and 2.5-in. height were used; that is, with about 6.25 square inch exposed area, of very thin and pure sheet-lead, so-called " test lead." These plates, after cleaning, were weighed on a chemical balance, reading accurately to about 0.5 milligrammes, then immersed in the electrolyte or the soil, the current passed through for a time varying from 60 hours to 390 hours; then the plates were taken out, washed with water and diluted acetic acid, (about 10%) dried, and again weighed. The total weight of the plate was about 6 grammes, and the amount dissolved usually several hundred milligrammes. Check tests showed that the amount of lead which can be dissolved chemically by acetic-acid washing does not exceed 1 or 2 milligrammes. The iron plates were cut to the same size, from transformer iron of 10 milligrammes thickness, having an average weight of 2.5 grammes. They were treated in the same manner, except that very dilute hydrochloric acid was used for washing.

As containing vessels, glass tumblers were used of about 250-cu. cm. volume, and the soil was kept moist by replacing the evaporation with distilled water. A number of tumblers were connected in series with an alternating-current circuit, and immersed in a water bath. The same number of tumblers with similar contents but not connected to the electric circuit were immersed in the bath, and used as a check to determine the spontaneous corrosion due to chemical action of the soil.

As source of 60-cycle current were used the lighting mains of the City of Schenectady; as source of 25-cycle current, a small inverted one-phase converter changing from direct to alternating current; as source of direct current, a mercury-arc rectifier operated from the 60-cycle circuit.

To give quantitative values, all the results are expressed in percentage of direct-current electrolysis; that is, the amount

TABLE I.

MAY 1 TO JUNE 18, 1906. LEAD PLATES. 6.25 SQ. IN. SURFACE. 1% SALT SOLUTIONS.

Electrolyte	Frequency cycles	Current amperes	Duration of test hours	Milligrammes lead dissolved per hour			% direct-current electrolysis		Ratio of total corrosion to chemical corrosion	Ratio of current to frequency
				chemical	total	electrolysis	total	electrolysis		
a	b	c	d	e	f	g	h	i	j	k
Ammonium Nitrate..............	60	0.3	60	2.18	3.14	0.96	0.271	0.084	1.44	5.0
		0.09	139		2.61	0.43	0.753	0.122	1.20	1.5
	25	0.3	150		10.65	8.47	0.918	0.737	4.88	12.0
		0.09	147		2.98	0.80	0.860	0.228	1.37	3.6
Ammonium Carbonate...........	60	0.3	60	0.102	2.14	2.04	0.184	0.176	21.0	5.0
		0.09	139		0.41	0.31	0.118	0.088	4.0	1.5
	25	0.3	150		6.70	6.60	0.578	0.570	65.8	12.0
		0.09	147		0.83	0.73	0.240	0.210	8.2	3.6
Sodium-Potassium Nitrate........	60	0.3	63	0.553	5.05	4.50	0.436	0.390	9.15	5.0
		0.09	140		1.90	1.35	0.547	0.392	3.43	1.5
	25	0.3	150		7.57	7.02	0.653	0.607	13.70	12.0
		0.09	149		2.66	2.11	0.765	0.610	4.82	3.6
Sodium Potassium Carbonate.....	60	0.3	77	0.535	0.73	0.20	0.063	0.017	1.37	5.0
		0.09	140		0.54	0.005	0.156	0.001	1.01	1.5
	25	0.3	150		0.67	0.14	0.058	0.012	1.25	12.0
		0.09	147		0.37	—0.16	0.107	—0.046	0.69	3.6
Sodium-Potassium Chloride.......	60	0.3	78	0.270	1.42	1.15	0.122	0.097	5.26	5.0
		0.09	140		1.08	0.81	0.312	0.234	4.00	1.5
	25	0.3	150		1.46	1.19	0.126	0.103	5.41	12.0
		0.09	147		1.09	0.82	0.314	0.234	4.03	3.6
Sodium-Potassium Sulphate.......	60	0.3	79	0.316	0.75	0.43	0.065	0.037	2.38	5.0
		0.09	140		0.595	0.28	0.172	0.079	1.88	1.5
	25	0.3	150		0.92	0.60	0.079	0.052	2.92	12.0
		0.09	147		0.65	0.33	0.187	0.095	2.06	3.6
Mixture........................	60	0.3	79	0.170	4.54	4.37	0.392	0.377	26.7	5.0
		0.09	140		1.35	1.18	0.390	0.338	7.9	1.5
	25	0.3	150		3.14	2.97	0.271	0.257	18.5	12.0
		0.09	147		1.58	1.41	0.455	0.408	9.3	3.6

TABLE II

MAY 1 TO JUNE 18, 1906. IRON PLATES. 6.25 SQ. IN. SURFACE. 1% SALT SOLUTIONS.

Electrolyte	Frequency cycles	Current amperes	Duration of test hours	Milligrammes lead dissolved per hour			% direct-current electrolysis		Ratio of total corrosion to chemical corrosion	Ratio of current to frequency
				chemical	total	electrolysis	total	electrolysis		
a	b	c	d	e	f	g	h	i	j	k
Ammonium Nitrate	60	0.3	63	1.841	3.77	1.93	1.21	0.62	2.05	5.0
		0.09	162		2.76	0.92	2.96	0.99	1.50	1.5
	25	0.3	143		3.66	1.82	1.18	0.586	1.99	12.0
		0.09	145		2.66	0.82	2.85	0.88	1.44	3.6
Ammonium Carbonate	60	0.3	63	0.	0.50	0.50	0.161	0.161		
		0.09	162		0.	0.	0.	0.		
	25	0.3	143		0.017	0.017	0.005	0.005		
		0.09	145		0.	0.	0.	0.		
Sodium-Potassium Nitrate	60	0.3	66	0.220	0.570	0.350	0.184	0.113	2.59	5.0
		0.09	162		0.283	0.063	0.304	0.068	1.29	1.5
	25	0.3	143		0.613	0.393	0.197	0.126	2.78	12.0
		0.09	145		0.462	0.242	0.496	0.260	2.10	3.6
Sodium-Potassium Carbonate	60	0.3	68	0.	0.	0.	0.	0.		
		0.09	162		0.	0.	0.	0.		
	25	0.3	143		0.007	0.007	0.002	0.002		
		0.09	145		0.014	0.014	0.015	0.015		
Sodium-Potassium Chloride	60	0.3	69	0.299	0.59	0.290	0.190	0.093	1.97	5.0
		0.09	163		0.307	0.008	0.330	0.009	1.03	1.5
	25	0.3	143		0.606	0.307	0.195	0.099	2.02	12.0
		0.09	145		0.439	0.140	0.471	0.150	1.47	3.6
Sodium-Potassium Sulphate	60	0.3	70	0.371	0.415	0.044	0.134	0.014	1.12	5.0
		0.09	163							
	25	0.3	143		0.644	0.273	0.207	0.088	1.73	12.0
		0.09	145							
Mixture	60	0.3	71	0.787	0.97	0.183	0.312	0.059	1.23	5.0
		0.09	163							
	25	0.3	143							
		0.09	145							

of metal dissolved per ampere-hour by alternating-current electrolysis is given in terms of the amount which 1 ampere-hour direct current should dissolve by Faraday's law: 3.86 grammes lead and 1.035 grammes iron per ampere-hour, assuming the valency of both metals as 2. In some tests, plates of one-half or one-quarter of these sizes were also used, in series with full-size plates, to determine the effect of various current-densities.

C. TESTS WITH SALT SOLUTIONS

One per cent. solutions in distilled water were used of those salts which may be expected in the soil.

1. 1% ammonium nitrate.
2. 1% " carbonate.
3. 0.5% sodium nitrate and 0.5% potassium nitrate.
4. 0.5% " carbonate and 0.5% " carbonate.
5. 0.5% " chloride and 0.5% " chloride.
6. 0.5% " sulphate and 0.5% " sulphate.
7. 0.25% ammonium nitrate, 0.25% ammonium carbonate, 0.125% sodium chloride, 0.125% potassium chloride, 0.125% sodium sulphate, 0.125% potassium sulphate,

referred to in the following as "mixture."

Eight sets of tests were made; four with lead plates and four with iron plates, under the following conditions:

a. 60 cycles 0.3 amperes, or 0.048 amperes per square inch
b. 60 " 0.09 " " 0.0144 " " " "
c. 25 " 0.3 " " 0.048 " " " "
d. 25 " 0.09 " " 0.0144 " " " "

It is interesting to note that considerable quantities of lead were found in solution only with ammonium nitrate, and small traces of lead with sodium-potassium carbonate. No lead went into solution with the other salts.

The results of the four sets of tests made with lead plates are given in Table I; the results of the tests with iron plates in Table II.

As indicated by Tables I and II, the electrolytic corrosion due to alternating current is very small compared with the electrolytic effect due to direct current, as shown by columns *h* and *i*; in no case did it equal 1%, in fact it rarely exceeded ½% of the direct-current electrolysis.

In general, then, iron is attacked less than lead. It therefore seems that, in general, with iron, alternating-current electrolysis is less to be feared, except in extreme cases; that is, with large currents passing between rails and iron pipes. With lead cables, the amount of corrosion indicated by Table I, would in many cases lead to a rapid destruction of the relatively thin cable sheet. The effect of alternating current on lead cables is therefore the more serious problem.

As shown in Table I, no general relation exists between the chemical corrosion, column *e*; that is the corrosion taking place without any current, and the electrical corrosion, column *i*, resulting from the passage of an alternating current. For instance, the chemical corrosion is about the same with sodium-potassium nitrate as with carbonate solutions; while the electrical corrosion is very high with nitrates, and practically neglible with carbonates.

TABLE III.

LEAD PLATES.

Electrolyte	Chemical corrosion mg. per hour	Total Corrosion % direct-current electrolysis			Electrical Corrosion % direct-current electrolysis		
		25	60	avg.	25	60	avg.
a. ammonium nitrate	2.18	0.889	0.512	0.700	0.483	0.103	0.293
b. ammonium carbonate	0.102	0.409	0.151	0.280	0.390	0.132	0.261
sodium potassium nitrate	0.553	0.709	0.491	0.600	0.608	0.391	0.500
" " carbonate	0.535	0.083	0.110	0.096	0.017	0.009	0.004
c. " " chloride	0.270	0.220	0.217	0.218	0.169	0.166	0.167
d. " " sulphate	0.316	0.133	0.119	0.126	0.074	0.058	0.066
Mixture	0.170	0.363	0.391	0.377	0.333	0.358	0.345
Avg. of *a, b, c, d*	0.717	0.413	0.250	0.331	0.279	0.115	0.197

Ammonium nitrate: large quantities of lead in solution.
Sodium potassium carbonate: traces of lead in solution.
Ammonium carbonate: very small traces of lead in solution in chemical, but none in electrolytic corrosion.
All others, including sodium potassium nitrate and chlorides: no traces of lead in solution

High current densities sometimes increase the electrical corrosion, as with ammonium salts, sometimes it decreases the corrosion, as with chlorides; but usually the current density has no appreciable effect.

In general, electrolytic corrosion is greater at lower frequency, but this is not always the case. For instance, with carbonates, where the electrolytic action is very low, high frequency seems to corrode more than low frequency; but with alkali nitrates, chlorides, and the mixture of salts, frequency has no appreciable effect.

Interesting is the comparison of the last two columns, *j*, the ratio of the total corrosion to the chemical corrosion, and *k*, the ratio of current to frequency; that is, the electric quantity per half wave. In most cases these two columns correspond closely; that is, the higher the quantity of electricity per alternation the greater the corrosion.

To investigate these relations still further, Table III gives the average values of corrosion, chemical, electrical, and total for 25 cycles and for 60 cycles. Table IV gives the average values for high- and for low-current densities, and their averages.

In the last row of these tables is given the corrosion which should be expected from the mixture, calculated as average of the corrosion due to its components. As seen, the mixture of different salts gives a very much lower chemical attack than the average attack of the components; that is, some salts, as the sulphates or carbonates, protect the lead against the attack by the nitrates. Electrolytically, however, the reverse is the case; this protective action of one salt against the attack by another does not seem to exist.

TABLE IV.

LEAD PLATES.

Electrolyte	Chemical corrosion mg. per hour	Total Corrosion % direct-current electrolysis			Electrical Corrosion % direct-current electrolysis		
		0.3 amp.	.09 amp.	avg.	0.3 amp.	.09 amp.	avg
a. ammonium nitrate	2.18	0.595	0.806	0.700	0.410	0.175	0.293
b. ammonium carbonate	0.102	0.381	0.179	0.280	0.373	0.149	0.261
sodium potassium nitrate	0.553	0.545	0.656	0.600	0.498	0.501	0.500
" " carbonate	0.535	0.061	0.131	0.096	0.014	0.022	0.004
c. " " chloride	0.0270	0.124	0.313	0.218	0.100	0.234	0.167
d. " " sulphate	.0316	0.072	0.180	0.126	0.045	0.087	0.066
Mixture	0.170	0.332	0.422	0.377	0.317	0.373	0.345
Avg. of *a*, *b*, *c*, *d*	0.717	0.293	0.369	0.331	0.232	0.161	0.197

The conclusion herefrom is, that it may be possible to protect lead cables chemically against spontaneous or chemical corrosion by surrounding the cables with alkali sulphates, for instance, but this affords no appreciable protection against electrolytic action by alternating current.

In Table I, the data on the electrical corrosion by ammonium nitrate are not very reliable, since ammonium nitrate attacks and dissolves lead chemically so rapidly that the additional attack by the alternating current cannot be determined accurately. In all other cases, the chemical corrosion is rather less than the electrical.

TABLE V.

LEAD PLATES—ORDER OF CHEMICAL CORROSION

		mg. per hour
1.	Ammonium nitrate	2.18
2.	Sodium-potassium nitrate	0.553
3.	Sodium-potassium carbonate	0.535
4.	Sodium-potassium sulphate	0.316
5.	Sodium-potassium chloride	0.270
6.	Mixture	0.170
7.	Ammonium carbonate	0.102

Table V, gives the order in which lead is attacked chemically by the different solutions. Nitrates attack the hardest, next come the alkali carbonates, and last is ammonium carbonate, and the mixture of salts in which some salts act as a protection against the others.

TABLE VI.

LEAD PLATES. ORDER OF ALTERNATING-CURRENT ELECTROLYTIC CORROSION

Total Corrosion					Electrical Corrosion				
Cycles		Amperes		Average	Cycles		Amperes		Average
25	60	0.3	0.09		25	60	0.3	0.09	
1	1	1	1	1	2	2	2	2	2
2	2	2	2	2	1	6	1	6	6
7	6	7	6	6	7	5	7	5	1
6	5	6	5	7	6	7	6	1	7
5	7	5	4.7	5	5	1	5	7	5
4	4	4		4	4	4	4	4	4
3	3	3	3	3	3	3	3	3	3

Table VI gives the order of attack by alternating current, the total corrosion, and the electrical corrosion. The different solutions are given by their numbers in Table V; that is, the numbers in Table VI represent the order of chemical corrosion.

As seen, the nitrates give the greatest corrosion, chemically as well as electrically. The other salts act electrically practically in reverse order to their action chemically: the alkali carbonates give the greatest chemical and the least electrical attack, next come the sulphates, then the chlorides.

TABLE VII

LEAD PLATES—ORDER OF TOTAL CORROSION

		% direct-current electrolysis	
	Number:	Total:	Electrical
Ammonium nitrate and sodium-potassium nitrate	1,2	0.650	0.397
Mixture, and ammonium carbonate	6,7	0.329	0.303
Sodium-potassium chloride	5	0.218	0.167
Sodium-potassium sulphate	4	0.126	0.066
Sodium-potassium carbonate	3	0.096	0

The approximate order of electrical corrosion of the different solutions is given in Table VII. Comparing Table VII with Table V, it is evident that, with the exception of ammonium nitrate and sodium-potassium nitrate the order of attack is reversed.

TABLE VIII.

LEAD PLATES. RATIOS.

Solution	Net corrosion, by current only					
	$\frac{\text{Low}}{\text{high}}$ frequency			$\frac{\text{High}}{\text{low}}$ current		
	0.3 amp.	0.09 amp.	avg.	25	60	avg.
1. Ammonium nitrate	8.77	1.87	4.69	3.23	.69	2.34
2. Ammonium carbonate	3.23	2.38	2.95	2.71	2.00	2.51
3. Sodium potassium nitrate	1.56	1.56	1.56	0.995	0.995	0.995
4. " " carbonate						
5. " " chloride	1.06	1.00	1.02	0.435	0.41	0.427
6. " " sulphate	1.41	1.20	1.28	0.55	0.47	0.517
7. Mixture	0.68	1.21	0.93	0.63	1.11	0.848
8. Avg. of 1, 2, 5, 6			2.43			1.44

Table VIII gives the ratio of electrical corrosion at low frequency to that at high frequency, and the ratio of corrosion at high current-density to that at low current-density; that is, gives the effect of frequency and of current-density.

ORDER OF RATIOS

Frequency ratio:	high current	1	2	3	6	5	7
	low "	2	1	3	7	6	5
	average "	1	2	3	6	5	7
Current ratio:	low frequency	1	2	3	7	6	5
	high "	2	7	3	1	6	5
	average "	2	1	3	7	6	5
Total average		2	1	3	7	6	5

Or, order of ratio: $\frac{\text{low}}{\text{high}}$ frequency, or $\frac{\text{high}}{\text{low}}$ current, that is, $\frac{\text{high}}{\text{low}}$ quantity of electricity per half wave:

Ammonium nitrate and carbonate.
Sodium-potassium nitrate.
Sodium-potassium sulphate, and mixture.
Sodium-potassium chloride.

As seen, the effect of frequency varies from 4.69 with ammonium nitrate to 0.93 with the mixture, and the effect of current density from 2.51 with ammonium carbonate, to 0.427 with alkali chlorides. In general, then, the order of salts in the two cases is similar; that is, decreasing frequency and increasing current-density have similar effects.

These tables show, however, that the effects of frequency and of current-density depend very largely on the chemical constitution. Ammonium salts show a very great increase of corrosion with increasing current-density, or decreasing frequency; whereas chlorides and sulphates show little effects of frequency, and a decrease of corrosion with increasing current-density. In general, the conclusions of the tests with lead plates in salt solutions are:

1. Chemical as well as electrical corrosion is greatest with nitrates. With other salts or mixtures of salts, the electrical corrosion is not proportional to the chemical corrosion, but, with the salts investigated, rather inversely proportional thereto; that is, where the chemical attack is considerable, the electrical action is more completely reversible than with a chemically less active electrolyte.

2. Current-density in general has no decided effect. High current-density increases the attack with some compounds, as ammonium salts, and decreases it with others, as chlorides and sulphates, provided the current density is not so high as to give

an appreciable increase of temperature, which then increases the corrosion.

3. Low frequency usually attacks more than high frequency. But the increase of corrosion due to lower frequency, entirely depends on chemical constitution, being largest with ammonium salts, and practically negligible with chlorides and sulphates.

4. Mixtures of salts frequently give a greatly reduced chemical corrosion, but give about the same or a higher electrical corrosion than their components; that is, chemical protection fails to protect electrolytically.

5. Iron is less attacked than lead, and is practically not attacked at all by carbonates.

D. EXPERIMENTS WITH DIFFERENT SOILS

Tests were made with different soils.

1. Garden soil, a clay loam, taken from Dr. Steinmetz's garden.

2. Street mud, collected from the surface of Schenectady's main street (State Street railway crossing), where the New York Central Railroad crosses the trolley line, and thus containing the accumulated effect of foot, horse, electric, and steam traffic.

3. Sub-soil, a sandy soil collected from below the street surface in the older part of Schenectady, where people lived for over 200 years, the soil containing the seepage of centuries.

4. A mixture, in equal volume, of these three soils.

The soil was kept moist by replacing evaporation with distilled water. It was considered that these three soils are about representatives of the more severe conditions to which lead pipes and cables in the soil are exposed. Four sets of tests were made, of lead plates, and of iron plates, with 60 cycles and with 25 cycles, all at one-tenth ampere current. The same size of plate was used as before and tested in the same manner. The results of these tests are abstacted in Table IX.

Very marked, however, is the effect of frequency. While at 60 cycles the electrical corrosion is very small, averaging less than 0.05% with lead plates, it is quite considerable at 25 cycles, averaging 0.222%.

The chemical corrosion of lead plates averages 0.148 milligrammes per hour, with 6.25 square inch plate surface. The total corrosion averages 0.085% at 60 cycles, and 0.216% at 25 cycles, and the electrical corrosion averages 0.047% at 60 cycles and 0.22% at 25 cycles. Especially marked is the enormous increase of corrosion with increase of temperature, which is investigated later.

Comparing the relatively small differences found in Table IX for different soils, with the great variations in the attack due to different salt solutions, in Table I and II, it was thought sufficient in the further investigations to use only one form of soil as typical—the mixture referred to above, but to investigate the effect of the addition of different substances.

TABLE IX.

JUNE 21 TO JULY 17, 1906. TESTS WITH DIFFERENT SOILS.
Plates, 6.25 sq. in. total surface; 0.1 ampere.

Electrolyte	Frequency cycles	Dur. of test	milligrammes dissolved per hour			% direct-current electrolysis	
		hours	chem.	total	elec.	total	elec.
a	b	c	e	f	g	h	i
Lead Plates.							
Garden soil	60	254	0.115	0.227	0.112	0.059	0.029
	25	244		0.908	0.793	0.235	0.205
Street mud	60	254	0.130	0.311	0.181	0.081	0.047
	25	244		1.250	1.120	0.324	0.290
Sub-soil*	60	254	0.224	0.462	0.238	0.120	0.062
	25	244		0.642	0.418	0.167	0.108
Mixture	60	254	0.121	0.310	0.189	0.080	0.049
	25	244		1.221	1.100	0.317	0.285
Iron Plates.							
Garden soil	60	254	0.078	0.169	0.091	0.163	0.088
	25	244		0.252	0.174	0.243	0.168
Street mud	60	254	0.036	0.099	0.063	0.095	0.061
	25	244		0.159	0.123	0.154	0.119
Sub-soil*	60	254	0.092	0.98	0.89	0.945	0.86
	25	244		1.99	1.90	1.93	1.83
Mixture	60	254	0.044	0.092	0.048	0.089	0.046
	25	244		0.087	0.043	0.084	0.042

* Appreciable rise of temperature by $I^2 r$.

E. SALT SOLUTIONS IN SOIL

Tests were therefore made by moistening the soil, not as before with distilled water, but with very diluted solutions of nitrates, and nitrites, carbonates, sulphates, and their mixture, to determine whether the presence of nitrates increases the corrosion, and the presence of carbonates or sulphates exerts a protective action. These experiments were made only at 25 cycles, 0.1 ampere, with the same size of lead and iron plates, of 6.25 square inch total surface, and are abstracted in Table X and XI.

The following solutions were used.

1. City water, (Schenectady) containing appreciable quantities of bicarbonate of calcium.
2. Solution of 0.1% potassium carbonate and 0.1% sodium carbonate in distilled water, a total of 0.2%.
3. Solution of 0.1% potassium sulphate and 0.1% sodium sulphate, in distilled water, a total of 0.2%.

TABLE X.

JULY 23 TO AUGUST 3, 1906. MIXED SOIL AND SALT SOLUTIONS.

25 cycles, 0.1 ampere, 6.25 sq. in. total plate surface.
Duration of test, 219.5 hours.
Mean temperature of water bath, 23.7° cent.

Electrolyte	Milligrammes dissolved per hour			% direct-current electrolysis	
a	chem. *e*	total *f*	elec. *g*	total *h*	elec. *i*
Lead Plates.					
City water	0.106	0.851	0.745	0.221	0.194
Potassium sodium carbonate	0.104	0.304	0.200	0.079	0.052
Nitrates and nitrites	0.166	0.716	0.550	0.186	0.143
Carbonates, nitrates and nitrites	0.128	0.481	0.353	0.125	0.092
Iron Plates.					
City water	0.073	0.262	0.189	0.253	0.183
Potassium sodium carbonates	0.117	0.288	0.171	0.278	0.165
Nitrates and nitrites	0.100	0.203	0.103	0.196	0.100
Carbonates, nitrates and nitrites	0.112	0.365	0.253	0.353	0.245

4. Solution of 0.1% ammonium nitrate, 0.05% potassium nitrite, and 0.05% sodium nitrite in distilled water, a total of 0.2%.
5. Solution of 0.1% potassium carbonate, 0.1% sodium carbonate, 0.1% ammonium nitrate, 0.05% potassium nitrite, 0.05% sodium nitrite, a total of 0.4%.
6. Solution of 0.1% potassium sulphate, 0.1% sodium sulphate, 0.1% ammonium nitrate, 0.05% potassium nitrite, 0.05% sodium nitrite, a total of 0.4%.

A comparison of Tables X and XI well illustrates the erratic character of the phenomenon of alternating-current electrolysis.

These two tests were made immediately after each other, under as nearly identical conditions as possible; the same frequency, current-density, etc., the same kind of soil, and practically the same temperatures. The chemical corrosion in both tests is about the same. In the second test it is somewhat less with lead plates, and somewhat more with iron plates, than in the first test. Wide differences are found in the electrical corrosion, not only in the numerical values, but also in the character of the effect produced by the different electrolytes.

In the first test, nitrates and nitrites exert a marked protective action on iron plates, which, however, disappears in the presence of carbonates. In the second test, nitrates and nitrites greatly increase the corrosion of iron plates. This may have something to do with the possibility of a passive state of the iron, and needs further investigation.

TABLE XI.

AUGUST 7 TO 23, 1906. MIXED SOIL AND SALT SOLUTION.

25 cycles, 0.1 amperes, 6.25 sq. in. total plate surface.
Duration of test, 333.5 hours.
Mean temperature of water bath, 22.3° cent.

Electrolyte	Milligrammes dissolved per hour			% direct-current electrolysis	
	chem.	total	elec.	total	elec.
a	*e*	*f*	*g*	*h*	*i*
Lead Plates.					
City water	0.085	1.160	1.075	0.300	0.278
Sulphates	0.073	0.505	0.432	0.131	0.112
Nitrates and nitrites	0.101	1.911	1.810	0.495	0.469
Sulphates, nitrates and nitrites	0.108	2.048	1.94	0.530	0.503
Iron Plates.					
City water	0.102	0.212	0.110	0.204	0.107
Sulphates	0.145	0.370	0.225	0.357	0.217
Nitrates and nitrites	0.158	0.483	0.325	0.466	0.313
Sulphates, nitrates and nitrites	0.155	0.642	0.487	0.618	0.469

Carbonates exert a marked protective action on lead plates, which is reduced if nitrates and nitrites are present; even then it is considerable. Sulphates also exert a protective effect on lead plates, but this protective action disappears, and the corrosion is increased in the presence of nitrates and nitrites. This agrees with previous experience in the tests with salt solutions. With iron plates, sulphates increase the corrosion.

It seems then that a certain protective action against alternating-current electrolysis of lead plates is exerted by carbonates and by sulphates. Since alkali salts are excluded from practical use by their solubility, a series of tests was undertaken to determine the effect that calcium carbonate and sulphate—chalk and gypsum—have on alternating-current electrolytic corrosion, when mixing these salts with the soil surrounding the lead cables.

F. CALCIUM SALTS IN SOIL

Tests were made on the effect produced by mixing 5% chalk or 5% gypsum, or both, with the soil used in alternating-current electrolysis. Some tests were also made by adding 5% Portland cement, and by adding 5% fertilizer, containing nitrates, phosphates, and ammonium compounds. Only lead plates were used, of the standard size of 1.25 in. by 2.25 in., with a current of 0.1 ampere.

TABLE XII.

AUGUST 25 TO SEPT. 9. 1906. LEAD PLATES.

25 cycles, 0.1 ampere, 6.25 sq. in total plate surface.
Duration of test, 362 hours.
Mean temperature of water bath, 23.1° cent.

Electrolyte		Milligrammes dissolved per hour			% direct-current electrolysis	
Solid *a*	Liquid	chem. *e*	total *f*	elec. *g*	total *h*	elec. *i*
Mixed soil.	**City water.....**	0.116	1.256	1.140	0.326	0.296
Mixed soil.	**Salt solution*..**	0.117	0.794	0.677	0.206	0.176
Mixed soil. +5% Chalk. **+ 5% Gypsum.**	City Water.....	0.079	0.245	0.166	0.0635	0.043
Mixed soil. **+ 5% Chalk.** **+ 5% Gypsum.**	**Salt solution*..**	0.126	0.704	0.578	0.182	0.150

* **0.5% solution of mixed potassium, sodium, ammonium, nitrates, nitrites, chlorides, as described above.**

Tests were made at 60 cycles, as well as at 25 cycles, to determine the effect of frequency. Some tests were made with plates of half and quarter size, in series with full-size plates, to determine the effect of current-density. The 60-cycle and 25-cycle tests, and the tests with full-, half-, and quarter-size plates, were made simultaneoutly, with the tumblers immersed in the same water bath so as to have the same temperature in all these tests.

Tests were made with the mixed soil, and also with the same soil by adding: 5% chalk, 5% gypsum, 5% Portland cement, 5% fertilizer: containing nitrates, phosphates, ammonia, 5% fertilizer, 5% chalk, and 5% gypsum. City water was used as liquid, except in a few tests, in which 0.5% salt solution was used, of the following constitution: ammonium nitrate 2, potassium nitrite 1, sodium nitrite 1, potassium chloride 1, sodium chloride 1, water 1194. Each tumbler contained about 120 cu. cm. of liquid, in addition to the soil.

TABLE XIII.

SEPT. 17 TO OCT. 3, 1906. LEAD PLATES.

0.1 ampere, 6.25 sq. in. total plate surface, half and quarter thereof.
Mean temperature of water bath, 22.7° cent. and 19.5° cent. respectively.
Liquid: City Water.

Electrolyte 22.7° cent. *a*	Frequency cycles *b*	Duration of test, hours *d*	Milligrammes dissolved per hour			% direct-current electrolysis		Ratio of attack 25–60 *l*
			chem. *e*	total *f*	elec. *g*	total *h*	elec. *i*	
Mixed soil........	25	277	0.159	1.451	1.292	0.376	0.335	
	60	306		0.996	0.837	0.258	0.217	1.54
Mixed soil + 5% chalk	25	277	0.155	1.088	0.933	0.282	0.242	
	60	306		0.711	0.556	0.184	0.144	1.68
Mixed soil + 5% gypsum.........	25	277	0.180	1.843	0.663	0.478	0.431	
	60	306		0.435	0.255	0.113	0.066	6.53
Mixed soil + 5% chalk + 5% gypsum.	25	277	0.134	1.544	1.410	0.400	0.365	
	60	306		0.499	0.365	0.129	0.095	3.84
Mixed soil + 5% Portland cement.	25	277	0.247	0.485	0.238	0.125	0.062	
	60	306		0.512	1.265	0.132	0.068	0.91
19.5° cent.								
Mixed soil + 5% fertilizer........	25	217	0.301	2.481	2.180	0.642	0.565	1.86
	60	234		1.474	1.173	0.383	0.304	
Mixed soil + 5% fertilizer + 5% chalk + 5% gypsum	25	217	0.303	3.638	3.335	0.940	0.864	
	60	234		2.483	2.180	0.643	0.564	1.53
Mixed soil, ½ size plates...........	25	217	0.162	1.289	1.127	0.334	0.292	
	60	234		1.119	0.957	0.290	0.247	1.18
Mixed soil, ¼ size plates..........	25	217	0.064	1.839	1.775*	0.476	0.460	
	60	234						

* Lead plates eaten to pieces. The pieces were collected as far as possible, but no doubt some escaped, hence this value is probably somewhat too large.

The three sets of tests are given in Tables XI, XII and XIII.

Table XII seems to show that the very diluted salt solution rather reduces the electrolytic corrosion.

The addition of chalk and gypsum to the soil exerts a marked protective action, which, however, practically disappears when a mixed salt solution is used instead of water.

Table XIII shows a moderate protective action against electrolytic corrosion, exerted by the addition of chalk to the soil.

Gypsum exerts a marked protective action only at 60 cycles, but increases the corrosion at 25 cycles.

Addition of chalk, as well as gypsum, gives the same effect as gypsum: a reduction of the corrosion at 60 cycles, but an increase at 25 cycles.

Organic materials, as fertilizer, greatly increase the electrolytic corrosion, and the addition of chalk and gypsum in this case still further increases the corrosion.

The effect of Portland cement is interesting: while the chemical corrosion is greatly increased by cement, from 0.159 to 0.247 milligrammes per hour, the electrolytic corrosion is greatly reduced and becomes very small at either frequency.

The current-density seems to have very little, if any, effect, since half-size plates, with the same current, give practically the same corrosion as full-size plates.

Especially interesting is the effect of frequency. In general, at lower frequency the corrosion is greater; but the order in which it varies with the frequency very largely depends on the chemical character of the soil. With soil only, the corrosion increases with decreasing frequency, but not any where near inversely proportional to the frequency. The addition of chalk or fertilizer seems slightly to increase the effect of frequency, but not to any great extent. Gypsum very greatly increases it, so that 60-cycle electrolysis nearly disappears, and the 25-cycle electrolysis is more than six times the 60-cycle electrolysis. Inversely, cement reduces the effect of frequency, so that both frequencies give practically the same attack.

It is worth noting the high values of electrolytic corrosion observed in soils containing fertilizer, especially when chalk and gypsum are added. These reach nearly 1% of direct-current corrosion at 25 cycles, and exceed one-half per cent at 60 cycles.

G. CONCLUSIONS

From the data recorded in Tables IX to XII, a number of comparisons on the effect of different constituents in the soil can be made. These are given in Tables XIV, XV, and XVI.

In these tables, the relative values of chemical, total, and electrical corrosion are given.

Table XIV. Effect of nitrates, nitrites, and similar compounds, as fertilizer. The corrosion is considerably increased, the chemical corrosion in all cases, the electrical corrosion in most tests, by an average of about 60%.

TABLE XIV.

Effect of Nitrates, nitrates and fertilizer:	Table No.	Frequency cycles	Corrosion: relative		
			chem.	total	elec.
Mixed soil only			1	1	1
Alkali nitrates and nitrites	X	25	1.56	0.84	0.74
Alkali nitrates and nitrites	XI	25	1.19	1.65	1.69
Alkali nitrates, nitrites and carbonate	X	25	1.21	0.57	0.48
Alkali nitrates, nitrites and sulphate	XI	25	1.27	1.77	1.81
Fertilizer	XIII	25	1.90	1.71	1.68
Fertilizer	XIII	60	1.90	1.48	1.40
Fertilizer and chalk and gypsum	XIII	25	1.91	2.50	2.57
	XIII	60	1.91	2.49	2.60
Average			1.61	1.63	1.62

TABLE XV.

Effect of carbonates, etc.	Table No.	Frequency cycles	Corrosion; relative		
			chem.	total	elec.
Mixed soil only			1	1	1
Alkali carbonates	X	25	0.98	0.36	0.27
Chalk	XIII	25	0.97	0.75	0.72
Chalk	XIII	60	0.97	0.71	0.66
Portland cement	XIII	25	1.56	0.33	0.19
Portland cement	XIII	60	1.56	0.51	0.31
Mixed soil containing gypsum			1	1	1
Chalk	XIII	25	0.75	0.84	0.85
Chalk	XIII	60	0.75	1.14*	1.14*
Mixed soil containing nitrates or fertilizer			1	1	1
Alkali carbonates	X	25	0.77	0.67	0.64
Chalk and gypsum	XIII	25	1.01	1.46	1.53
Chalk and gypsum	XIII	60	1.01	1.68	1.85

* Ratios of two small values, therefore less reliable.

The presence of nitrates, fertilizers etc., in the soil is therefore objectionable.

Table XV. Effect of carbonates, and, in general, alkaline compounds.

Carbonates and alkaline compounds, as far as observed, always reduce the electrolytic corrosion of lead, and also the chemical corrosion; that is, they exert a protective action. This is most pronounced with alkali carbonates and cement, the latter, however, greatly increasing the chemical corrosion.

The protective action of carbonates seems to decrease in the presence of sulphates, nitrates, etc., and is in general not sufficiently large to give promise of a method of chemically protecting lead plates against alternating-current electrolysis, by surrounding them with calcium carbonate or hydrate.

Table XVI. Effect of sulphates. Sulphates sometime exert a protecting action, but sometime increase the corrosion. The latter seems to be the case in the presence of nitrates.

TABLE XVI.

Effect of sulphates, etc.	Table No.	Frequency cycles	Corrosion; relative		
			chem.	total	elec.
Mixed soil only			1	1	1
Alkali sulphates	XI	25	0.86	0.44	0.40
Gypsum	XIII	25	1.13	1.27	1.29
Gypsum	XIII	60	1.13	0.44	0.30
Chalk and gypsum	XII	25	0.68	0.20	0.15
Chalk and gypsum	XIII	25	0.84	1.07	1.09
Chalk and gypsum	XIII	60	0.84	0.50	0.44
Mixed soil containing nitrates or fertilizer			1	1	1
Alkali sulphates	XI	25	1.07	1.07	1.07
Chalk and gypsum	XIII	25	1.01	1.46	1.53
Gypsum	XIII	60	1.01	1.68	1.85

In Table XVII are calculated the tests made with soil only, without additional protective or destructive compounds. These give an average spontaneous or chemical corrosion of 0.117 milligrammes per hour, or 0.0188 milligrammes per hour and square inch plate surface, and an average total corrosion, at 25 cycles, of 0.312%, or an electrical corrosion of 0.280% of direct-current electrolysis.

Assuming the specific gravity of lead as 11.4, under these conditions, by chemical corrosion, in 10 years a layer of lead of 0.009 in. thick would be consumed. That is, under average conditions, chemical corrosion of lead cables could be neglected.

Electrically, at a current-density of 1 ampere per square foot, 25 cycles would, in 10 years, destroy an additional layer of lead 0.07 in. thick. In the worst case observed this would increase to 0.22 in. or nearly 0.25 in.; that is, would eat through the cable armor long before this time.

With a current-density of 10 amperes per square foot, a cable armor ⅛ in. thick would in average be eaten through in 1.8 years, but in the extreme case may be eaten through in 0.57 years, or 7 months.

H. EFFECT OF TEMPERATURE

Since in the preceding tests, especially in the first set of tests, before a water bath was used, it was noticed that the values of alternating-current electrolytic corrosion were high, whenever the temperature of the cell is increased by its $I^2 R$ loss, some tests were made on the effect of temperature by heating the water bath in which the cells were immersed. The temperature of the bath fluctuated between 36° and 42° cent. with an average of 39.5° cent.

TABLE XVII.
LEAD PLATES. MIXED SOIL. 25 CYCLES.

	Corrosion:		
	chemical	total	electrical
Table No.	Milligrammes per hour	% direct-current electrolysis	
IX	0.121	0.317	0.285
X	0.106	0.221	0.194
XI	0.085	0.300	0.278
XII	0.116	0.326	0.296
XIII	0.159	0.376	0.335
XIII	½ size	0.334	0.292
Average...	0.117	0.312	0.280
Maximum corrosion observed..	0.303	0.940	0.864

Tests were made with mixed soil, and with mixed soil and 5% fertilizer added, at 0.1 ampere, 25 cycles, and without current, and gave the results recorded in Table XVIII.

As seen from Table XIX, and comparing these results with the average values of previous experiments, the chemical as well as the electrolytic corrosion is very greatly increased by the increase of temperature.

I. CONCLUSIONS

The following conclusions seem to be warranted from the preceding investigations.

1. Alternating-current electrolysis is not a phenomenon like direct-current electrolysis, on which definite quantitative general laws can be formulated; but is of the character of a secondary effect; that is, the action of the positive half wave is not quite reversed by the action of the negative half wave, leaving a small difference, rarely exceeding one-half percent of the electrolytic action of an equal direct current.

TABLE XVIII.

OCT. 20 TO 29, 1906. LEAD PLATES.

25 cycles, 0.1 ampere. 6.25 sq. in. total plate surface.
Duration of test, 208 hours.
Water bath heated electrically, mean temperature 39.5° cent.
Liquid, city water.

Electrolyte	Milligrammes dissolved per hour			% direct-current electrolysis	
	Chemical	Total	Electrical	Total	Electrical
a	*e*	*f*	*g*	*h*	*i*
Mixed soil	0.296	4.11	3.81	1.065	0.987
Mixed soil + 5% fertilizer	0.393	4.53	4.14	1.175	1.075

Under the conditions of the investigation, which were chosen to represent as nearly as possible actual service conditions of lead cables, alternating-current electrolysis varies from practically nothing to somewhat less than 1% of direct-current electrolysis. Since electrolytic action of the alternating current appears as a small difference between two large and nearly equal quantities, the action of the positive and of the negative

TABLE XIX.

Electrolyte	Temperature degrees centigrade	Corrosion % direct-current electrolysis			Corrosion, ratio		
		chemical	total	electrical	chemical	total	electrical
Mixed soil	22.3°	0.117	0.312	0.280	1	1	1
	39.5°	0.296	1.065	0.987	2.53	3.41	3.52
Mixed soil + 5% fertilizer	19.5	0.301	0.642	0.565	1	1	1
	39.5	0.393	1.175	1.075	1.30	1.83	1.90

half wave, a very small variation in the action of either half wave makes a very large difference in the result, and this probably accounts for the very large variation in the electrolytic action of alternating current compared with the constancy of the electrolytic action of direct current.

2. Alternating-current electrolysis, when expressed quantitatively, or in per cent, of the action of an equal direct current, varies very greatly with the chemical character of the electrolyte. The nitrates and similar compounds, as fertilizers, tend to increase electrolytic corrosion; carbonates and, in general, alkaline reaction of the soil, decreases the corrosion; that is, exert a protective action.

This protective action against alternating-current electrolysis is decreased by the presence of nitrates, etc., and is hardly sufficient to be of practical use for protecting lead cables against attack by alternating current.

3. In general, lead is more attacked than iron, and the latter shows still more erratic behavior than lead, probably due to the existence of a passive state.

4. Alternating-current electrolysis under conditions representing as nearly as seems feasible the conditions of lead cables in the soil, does not appreciably depend upon the current-density, but is practically independent thereof, except indirectly, in that very high current densities may by an increase of temperature give an increased corrosion.

5. In general, electrolytic corrosion by alternating currents increases with decrease of frequency. This increase with decreasing frequency does not follow a general law, but depends largely upon the chemical character of the electrolyte. It may be enormous; that is, 25-cycle current gives many times greater corrosion than the same current at 60 cycles. Or it may be very small and negligible. In some instances, 60-cycle current seems to give a somewhat greater attack than 25-cycle current.

In general, ammonium salts and nitrates seem to give a very great increase of electrolytic corrosion with decreasing frequency, while carbonates and soils with alkaline reaction, as containing cement, may give little or no increase of corrosion with decreasing frequency.

6. Chemical corrosion by the soil, and electrolytic corrosion by alternating current increases very greatly with increasing temperature of the soil.

J. Electrical Protection

Since the attempt to find a method of protecting lead chemically against alternating-current corrosion by mixing compounds as chalk, etc. with the soil surrounding the lead cable did not seem very hopeful, an investigation was made on the possibility of electrical protection against alternating-current electrolysis. With the tests recorded in Table XIV, a test was made on three tumblers, with ordinary mixed soil—one on 25 cycles, one on 60 cycles, and one without current, to check regarding spontaneous or chemical corrosion. In these tests a piece of sheet zinc, of about half the size of the lead plates was connected electrically with one of the lead plates. The idea was that a local action between lead and zinc would produce a direct current between lead and zinc, with the lead as negative, and thus exert a protective action.

The results of this test were:

TABLE XX.

Sept. 19 to Oct. 3, 1906.

Total time of immersion of plates, 234 hours.
Duration of test with 60 cycles, 234 hours, 0.1 ampere.
Duration of test with 25 cycles, 217 hours, 0.1 ampere.
Temperature of water bath, 19.5° centigrade average.
Size of lead plates, 1¼ in. by 2½ in., or 6.25 sq. in. total exposed surface.
Size of zinc plates, about ½ in. by 3 in.
Electrolyte, mixed soil, city water.

No. of tumbler	No. of plate	Material	Frequency cycles	Duration of test hours	Weight of plate before test	Weight of plate after test	Difference total mg.	Electrical cor. mg.	Dissolved per hour elec. mg.	% Direct-current electrolysis
					in grammes					
7	13	lead	25	217	5.565	4.960	605	523	2.41	0.62
	14	lead			5.883	5.792	91	9	0.0415	0.0107
	14^1	zinc			5.885	5.685	200			
8	15	lead	0	234	5.095	4.992	103	avg.		
	16	lead			5.892	5.831	61	82	(.351)	
	16^1	zinc			5.734	5.067	67			
9	17	lead	60	234	5.046	4.709	337	255	1.09	0.282
	18	lead			5.900	5.817	83	1	0.0043	0.0011
	18^1	zinc			5.769	5.649	120			

While with a zinc plate connected to the lead plate a decrease of the attack should be expected—since the alternating current divides between the zinc plate and the lead plate, and the lead plate receives only a part of the total current—still the difference between the electrical corrosion of the lead plate protected by contact with the zinc plate, and the unprotected lead plate, is startling.

At 25 cycles the unprotected lead plate gives 0.623%, at 60 cycles 0.28%, of the electrolytic attack of a corresponding direct current, while the lead plate in contact with the zinc plate is practically completely protected; that is, is attacked practically no more than it would without any current, by the chemical action of the soil.

To investigate this action still further, a series of tests was made in which a small direct current was superimposed upon the alternating current. A transformer was interposed between the inverted converter which gives the 25-cycle alternating current, and the electrolytic cells, to separate the alternating-current circuit electrically from the direct-current circuit, and a small direct current sent through the cells in a divided circuit.

The 25-cycle alternating current consisted of 0.1 ampere; 0.005 ampere direct current was used, divided so that some of the cells received 1.14 milliamperes, while the others received 3.86 milliamperes, and the undivided direct current of 5 milliamperes passed through some cells without alternating-current. Resistances were inserted in both the alternating-current and the direct-current circuit, and a very high reactance of about $x = 50,000$ ohms, in the direct-current circuit.

The same kind of mixed soil as in the former tests was used as an electrolyte and also this soil mixed with 5% Portland cement, and this soil mixed with 5% fertilizer. City water was used as liquid. In some tests, half-size and quarter-size plates were used to get the effect of current-density. Results of the test are given in Table XXI.

The results of tests in Table XXI are extremely interesting. As seen, in many of these tests the electrical corrosion is negative: the total corrosion is less than the chemical corrosion; or in other words, if upon the alternating current a very small direct current is superimposed the total corrosion of the lead is reduced below the value which would exist with no current at all flowing.

With a direct current equal to 3.86% of the alternating current added thereto, the protection is complete; that is, in every case the lead is attacked less, sometimes less than half as much as it would be attacked spontaneously by the chemical action of the soil. Even with a direct current of only 1.14%, or about 1/90 of the value of the alternating current, the protection is

TABLE XXI.

Oct. 9 to 14, 1906. Lead Plates

25-cycle alternating current, and direct current. Duration of test, 111 hours.
Time of immersion, 114 hours. Mean temperature of water bath, 18.2° cent.

No. of tumbler	Electrolyte	Size of plate	Amperes		Mg. lead dissolved		Mg. dissolved per hour		% direct-current electrolysis		Ratio of total corrosion to chemical corrosion
			A.C.	D.C.	total	elec.	total	elec.	total	elec.	
1	Soil	¼	0.1	0.00114	481 48	449 16	4.28 0.428	4.08 0.144	1.11 0.111	1.035 0.0373	1.530
2	Soil	½	0.1	0.00114	565 67	519.5 21.5	5.08 0.594	4.68 0.194	1.32 0.154	1.215 0.0503	1.485
3	Soil	1	0.1	0.00114	583 88	512 17	5.23 0.776	4.61 0.153	1.355 0.201	1.195 0.0397	1.245
4	Soil and cement	1	0.1	0.00114	621 90	503.5 —27.5	5.57 0.785	4.54 —0.248	1.445 0.204	1.175 —0.0643	0.760
5	Soil and fertilizer	1	0.1	0.00114	605 69	534 —2.	5.43 0.605	4.81 —0.018	1.41 0.157	1.245 —0.0047	0.973
6	Soil	¼	0.	0.	33 31		0.280				
7	Soil	½	0.	0.	41 50		0.400				
8	Soil	1	0.	0.	71 71		0.623				
9	Soil and cement	1	0.	0.	138 97		1.033				
10	Soil and fertilizer	1	0.	0.	71 71		0.623				
11	Soil	1	0.1	0.00386	1844 65	1773 —6	16.6 0.569	16.0 —0.054	4.30 0.147	4.15 —0.014	0.915
12	Soil and cement	1	0.1	0.00386	1759 50	1641.5 —67.5	15.8 0.425	14.8 —0.608	4.10 0.110	3.83 —0.158	0.411
13	Soil and fertilizer	1	0.1	0.00386	1911 29	1840. —42	17.2 0.245	16.6 —0.378	4.46 0.064	4.30 —0.098	0.393
14	Soil	1	0.	0.005	2366 87	2295 16	21.3 0.767	20.7 0.144	110.5	107.5	1.235
15	Soil and cement	1	0.	0.005	2356 93	2238.5 —24.5	21.2 0.812	20.2 —0.221	110.0	104.5	0.788
16	Soil and fertilizer	1	0.	0.005	2580 49	2509. —22.	23.2 0.425	22.6 —0.198	120.0	117.0	0.583

practically complete, and the additional corrosion due to the alternating current is small compared with the chemical attack, or even negative; that is, the total attack is decreased.

This protection by a small direct current is especially effective under these conditions of the soil, where the electrolytic or chemical attack is especially great. With fertilizers, or with cement in the soil, a direct current of 1/90 the value of the alternating current reduces the corrosion below the value which it would have without any electrolytic action.

Comparing the results of Table XVII with those of XXI, it follows for mixed soil and a 25-cycle alternating current of 0.1 ampere:

Electrolytic corrosion by 25-cycle alternating current Table XVII, 0.280% of direct-current electrolysis.

Electrolytic corrosion by 25-cycle alternating current with the addition of 1.14% direct current reduced to − 0.042% of direct-current electrolysis.

Electrolytic corrosion by 25-cycle alternating current with the addition of 3.86% direct current reduced to 0.014% of direct-current electrolysis.

It must be noted, however, that the spontaneous or chemical corrosion in the test Table XXI, was, with mixed soil, considerably higher than the average of the previous tests.

Regarding the effect of current-density, Table XXI again shows this to be absent. The electrolytic corrosion for current-densities varying from 1 to 4; that is, with full, half- and quarter-size plates and the same current of 0.1 ampere, is of the same order.

Quarter-size plates, with a current-density of 0.1 ampere per 1.6 sq. in. or 9 amperes per sq. ft., give 0.0373% of direct-current electrolysis.

Half-size plates, with a current density of 0.1 ampere per 3.2 sq. in., or 4.5 amperes per sq. ft., give 0.0503 % of direct-current electrolysis.

Full-size plates, with a current density of 0.1 ampere per 6.25 sq. in. or 2.3 amperes per sq. ft. give 0.0397% of direct-current electrolysis.

These values do not point to a definite variation of the attack with the current-density.

The last three tests, 14 to 16, were made with direct current only, and show an electrolytic attack which is greater than the theoretical calculated from Faraday's law; that is, the corrosion of lead by direct current is greater than the theoretical value, and the direct current does not only dissolve the theoretical amount of lead, according to Faraday's law, but also increases the spontaneous corrosion due to the chemical action of the soil, especially in the presence of nitrates, etc.

Regarding the protective action of a small direct current, against alternating-current electrolysis, it must be understood that this is not due to maintaining the lead negative against the ground. It is obvious that the lead would be protected against corrosion, if upon the alternating current a direct current were superimposed sufficiently large to maintain the lead always negative. This, however, would require a direct current more than $\sqrt{2}$ times the alternating current, which is not practical. From the previous tests, it appears that a direct current of 1.5% of the alternating current gives practically complete protection against the electrolytic action of the alternating current. Such a small direct current would not appreciably change the duration of the successive half waves of alternating current, but the lead would still be positive for practically half the time; and with such a current graphically superimposed upon the alternating current, the eye would hardly see the difference in size of the two half waves of the resultant current.

It seems that a very small increase of the negative half wave over the positive half wave of the current is sufficient to make the negative half wave completely reverse and thus neutralize the action of the preceding positive half wave.

To investigate this phenomenon further in an experiment of larger magnitude, the following test was made. A lead plate was used, of 10¾-in. width, and 13¾-in. height, giving a total surface of about 2 sq. ft. It was immersed between two sheet-iron plates, as other terminal, of 5 in. by 14 in. each, in a large earthenware vessel. The lead plate was cut in two vertically, and the two halves spread apart, and in the space three small lead plates, of about 6 sq. in. each, inserted in the soil without any electrical connection, to serve as check for the chemical corrosion, due to the soil.

As an electrolyte, I used garden soil, a clay loam, with some sand, a considerable amount of street mud, and some fertilizer added. Four-ampere, 25-cycle alternating current was used and superimposed thereon, 0.06 ampere or 1.5% direct current.

The current was kept on the circuit for 20 days, from Oct. 20th to Nov. 9th, 1906, during which time the alternating current varied between 3.8 and 4.0 amperes, while the direct current remained constant at 0.06 ampere.

During the test the temperature of the soil was about 10° higher than that of the air and averaged 27.0° cent. Masses of marsh gas, with a considerable quantity of sulphuretted hydrogen, were evolved; that is, decay of organic matter took place in the soil. Evaporated water was replaced.

After the test, the lead plates were found covered with a black deposit, to which the sand stuck so that it could not be washed off, even with boiling water. With very diluted HCl, this black deposit was dissolved with the evaporation of large quantities of H_2S, and the acid was colored greenish black, as if iron had been carried across by the current and deposited as sulphide.

The test gave the following results:

Size of lead plates, both sides:	294	sq. in.
Total weight, before test	208.756	grammes
" " after "	206.975	"
Weight dissolved	1.781	"
Duration of test	470	hours
Average 25 cycles current	3.9	amperes

A. Ampere-hours, alternating current	1833
" " direct current	28.2
Dissolved per ampere-hour alternating current	.972 mg.
Theoretical attack per ampere-hour direct current	3860 mg.
Total corrosion, per cent. of direct-current electrolysis	0.0252%

B. Weight dissolved per hour and sq. in.	0.0129 mg.		
Check plates, number	1	2	3
Location	top	middle	bottom
Surface, sq. in. both sides	6.24	6.72	6.72
Weight before test	4.575	4.797	4.763
" after "	4.527	4.759	4.722
" dissolved	48	38	41
" " per sq. in. and hour	0.0160	0.0118	.0127
Average	0.0134 mg.		
Leaves as electrical corrosion, per sq. in. and hour	−0.0005 mg.		
Amperes per sq. in., 25 cycles	0.0132		
Electrical corrosion, per cent. direct current electrolysis	−0.001%		

It seems to follow herefrom that a direct current superimposed on the alternating current and equal to 1.5% of the alternating current, perfectly protects the lead plates against electrolytic attack by 25-cycle current; so that the corrosion of the lead plates in the soil is reduced to the value of corrosion which would take place spontaneously by the chemical action of the soil, or even less.

From Table XIX it follows that the average electrolytic corrosion in ordinary soil, by 25-cycle alternating current, is 0.280% (in soil containing fertilizer, as in the last test, it is greater). 1833 ampere-hours would therefore dissolve electrically

$$1833 \times 0.0028 \times 3.86 = 19.85 \text{ grammes of lead.}$$

With a chemical corrosion of 0.0134 mg. per square inch an hour, observed, 294 sq. in. would lose in 478 hours,

$$0.0134 \times 294 \times 470 = 1850 \text{ mg} = 1.85 \text{ grammes.}$$

Without protective action by superimposed direct current, the total corrosion of the lead plates during the 20 days' test therefore should be 21.70 grammes.

By the superposition of 28.2 ampere- hours direct current, or 1.5% of the alternating current, this was reduced to 1.78 grammes.

Or to 8.2% of its former value, showing strong protective action of the superimposed direct current.

A paper presented at the 214th Meeting of the American Institute of Electrical Engineers, New York, March 1, 1907.

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ELECTROLYTIC CORROSION OF IRON AND STEEL IN CONCRETE

BY A. A. KNUDSON

In these days of wide and rapidly growing use of reinforced concrete and hydraulic cements in all kinds of structures, the question often comes up as to whether concrete will afford to iron and steel the same protection from stray currents of electricity that it does ordinary corrosion or rust. In the practice of investigating movements and results of currents upon under ground pipes and other structures, several instances have come to our notice where damage has been caused by electrolytic action upon metals covered or incased in concrete or Portland cement.

During the last year we have frequently been asked about the probabilities of electrolysis upon various underground structures where the use of cement or concrete was being considered or had been used. In view of the importance of this question, therefore, we have thought it would be of service to those who are interested in the subject if more light were thrown on the true value of concrete as a supposed insulator. With a desire to obtain some definite data as to the amount of current and time necessary to cause corrosion upon metals encased in concrete or hydraulic cements, and also to test their value as electrolytes, we have made some laboratory experiments, and herewith give the results, trusting they may be of some value.

In March, 1903, blocks of concrete containing iron tubes were prepared by the writer for this purpose. These blocks or samples were made of equal parts of portland cement and sand. They were made in ordinary metal pails slightly larger at the top than at the bottom. In the center of each block was placed a 2-in. wrought-iron pipe. The dimensions of each block and the surface of iron buried are given in plan and sectional drawing, Fig. 1, and will not require further explanation; the cuts show blocks and pipes after the tests. A few preliminary tests at this time indicated that a series of tests might bear important results, and as we lacked opportunity for making daily tests and observations, they were sent to the Electrical Testing Laboratories of this city where excellent facilities were had for making the required measurements. Preliminary tests were made with the object of "feeling our way" and of selecting such amount of current for the series as seemed advisable. These preliminary tests not being especially important, the details are not given, but from the information obtained it was decided to commence a series of tests extending over a time of 30 days with the three blocks immersed, and under the following conditions:

Block 2, Fig. 2, was immersed in fresh water and Block 4 in sea water. These were connected in series, with 0.1 ampere continuously flowing through them. Block 3, Fig. 3, was also immersed in sea water, but no current was sent through it. This was for the purpose of comparison after the blocks were broken open. The arrangement of the circuit is shown in Fig. 4.

These tests were commenced on February 1, 1906, and ended March 2, 1906. The results of importance upon this first group of blocks were found in the gradual disruption of the concrete, as shown by the cracks as time went on, and the appearance of electrolysis and loss in weight of the iron tubes of both No. 2 and No. 4 when the tests were concluded. Block 4 is not shown, it being quite similar to the others. During the test these cracks were noted as follows: on the 17th day a small crack down one side of Block 2 was observed. On the 27th day this crack in No. 2 had a maximum width of ⅛ in. and extended clear down one side, across the bottom, and nearly to the top of the other side. Two cracks also appeared in No. 4. This disintegration of the concrete was a genuine surprise. The report furnished by the laboratory on this first set of experiments concludes as follows:

> After the conclusion of this test which extended over thirty days time, the blocks were removed, and after allowing them to dry they were broken open. It was found to be quite easy to break open blocks Nos. 2 and 4 which had already become cracked. Block No. 3 which had not been subjected to electrolysis was broken with the greatest difficulty. Blocks Nos. 2 and 4 showed on their interior strong evidences of electrolytic

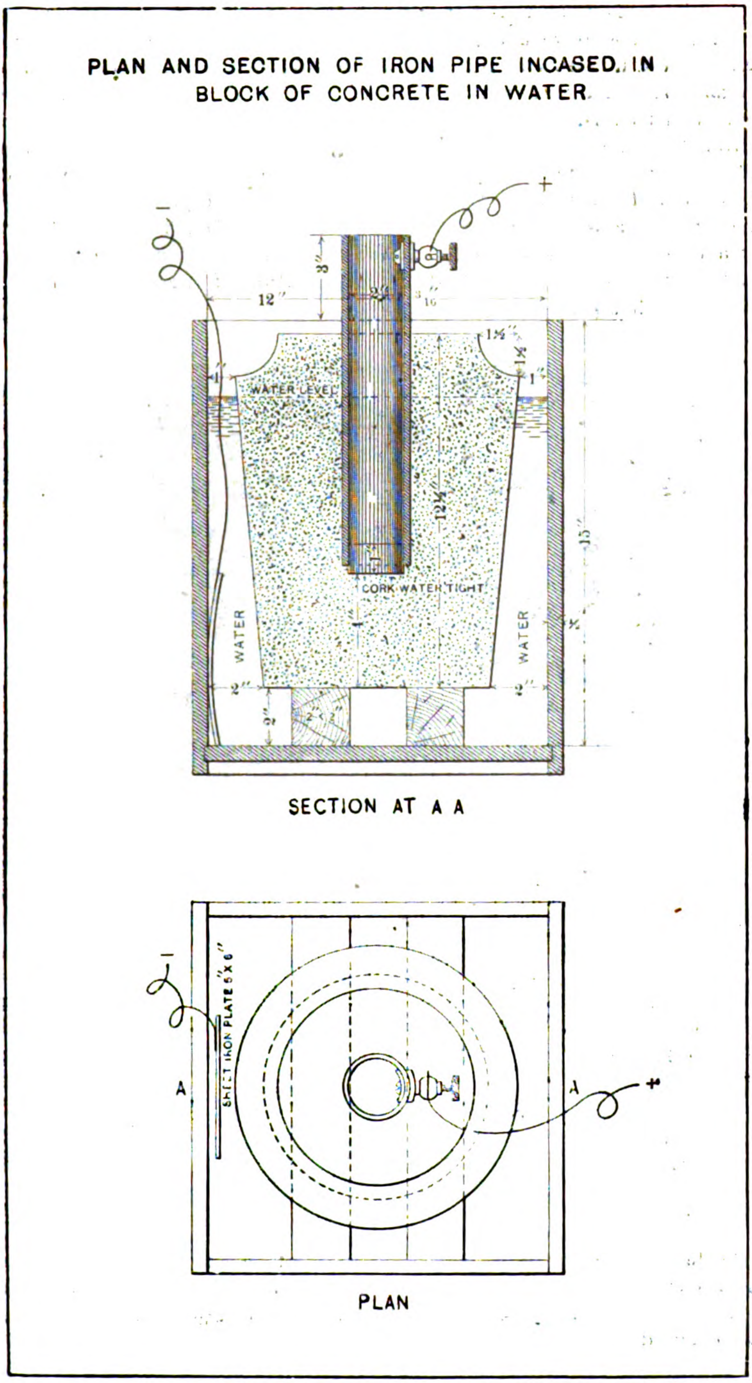
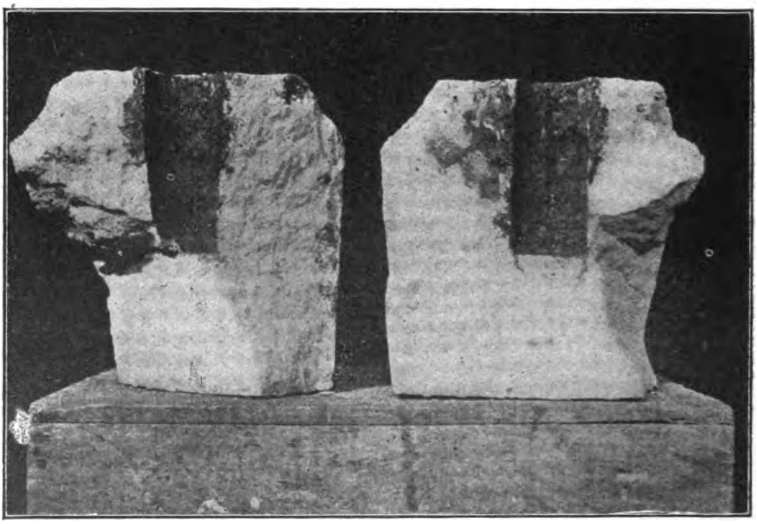

PLAN AND SECTION OF IRON PIPE INCASED IN BLOCK OF CONCRETE IN WATER
−
+
3"
12"
2¼"
3/16"
1½"
1½"
1"
1"
WATER LEVEL
12¾"
15"
CORK WATER TIGHT
1"
½"
WATER
WATER
2"
2"
2"
2"×2"
SECTION AT A A
−
SHEET IRON PLATE 5"×6"
A
A
+
PLAN

Fig. 1.

action in the form of what was apparently a deposit of iron rust extending from the pipe toward the outside of the block. Along certain lines which acted like lines of cleavage, the cement was found to be softened so that it could readily be cut or scraped with a knife. This softening was such that the point of a blade of a pocket knife could be inserted into it far enough so that the knife was supported in an upright position. The pipes enclosed in Nos. 2 and 4 were found to be considerably corroded. A portion of the scale on the corroded parts of these pipes was removed and the pipes were weighed. The pipe in Block No. 3 was as bright as a new pipe. The concrete showed no evidences of a deposit of iron rust. An idea may be formed of the condition of the concrete blocks from the photographs given herewith.



(Block 2) FIG. 2.

Weighing of the pipes had been made by Mr. Knudson before casting them in the blocks. Weighings made at the conclusion of the experiment, together with these initial weighings, are given in the following table:

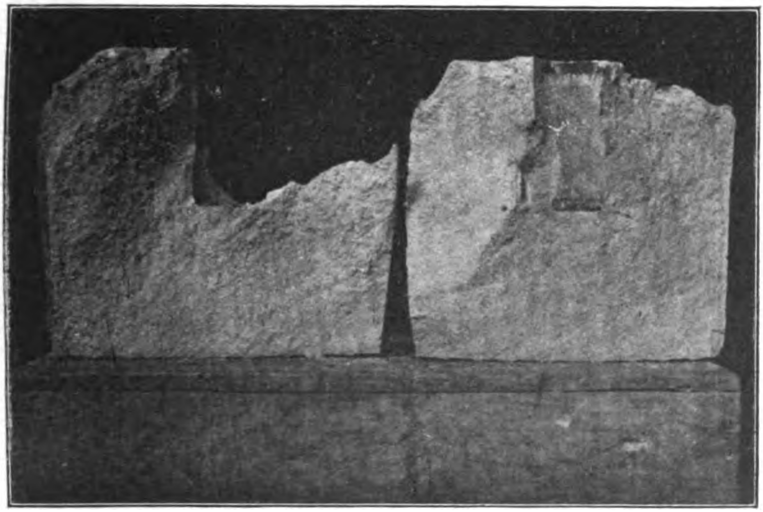
	No. 2 fresh water.	*No. 4.salt water.*
Initial.............	3 lb. 12.50 oz.	3 lb. 7.5 oz.
Final..............	3 " 10.95 "	3 " 6.4 "
Loss...............	1.55 "	1.1 "

As has been said above, the scale was not entirely cleaned off from pipes Nos. 2 and 4 before the final weighing was made, so that the loss in weight does not represent the entire amount of the electrolysis which had occured.

The results of these experiments seemed so important that it was thought best before drawing conclusions to have the tests repeated, and therefore another set of experiments similar to the first, was made to see how the data would compare.

SECOND SET OF EXPERIMENTS

In this case two blocks of concrete were prepared, numbered 5 and 6 (Block 6 not shown). These were made the same as the others except that Rosendale cement was used, called in the trade "Brooklyn Bridge Brand." The object of using a different cement was to see if there was any change in the results that could be attributed to the use of a different brand of cement. In these tests more careful and more frequent measurements were employed than in the first set of experiments. They were commenced on April 12th, 1906. Two readings every 24 hours were made through the entire 30 days, and the appearance of the blocks was closely watched. The source of current, as in the first test, was from a storage-battery, and the pressure was increased or decreased according to the resistance, in order to maintain a constant current of 0.1 ampere.



(Block 3)
(no current)

FIG. 3.

The variation of resistance in both blocks during the test of 30 days is important. Such changes are graphically represented in curve sheet Fig. 6, the figures showing ohms are given as relative, as they may not quite accurately represent the true values. They were obtained by simply dividing the volts by the 0.1 ampere. It was found in the preliminary trials that resistance measurements by the usual methods, such as the Wheatstone Bridge, were not accurate, owing to strong polarizing effects. For this reason the resistances as shown by these curves while not considered absolutely accurate in every case, are sufficiently so for our purpose of examination and study.

The curve in Fig. 7 represents the sudden fall or practical breakdown of concrete as insulation in 48 hours. The measurements in this test were made by the Wheatstone Bridge, using alternating current and a telephone receiver. They are considered fairly accurate.

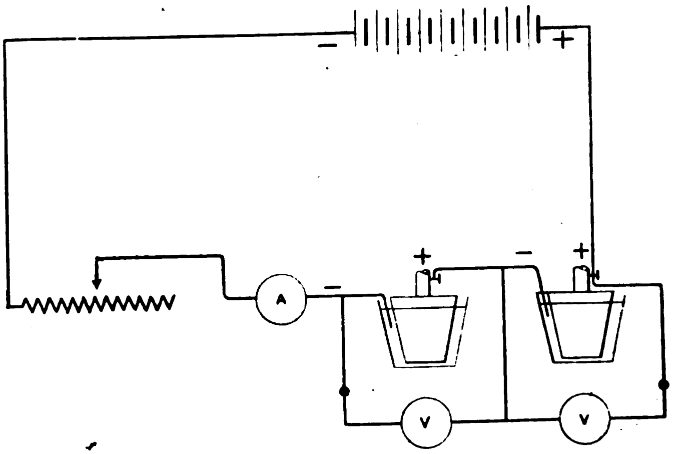


Fig. 4.

Quoting from the report on this second series of tests, the following notes are of interest:

Second day of test. Water appeared around the pipe of No. 5, having soaked through the concrete.

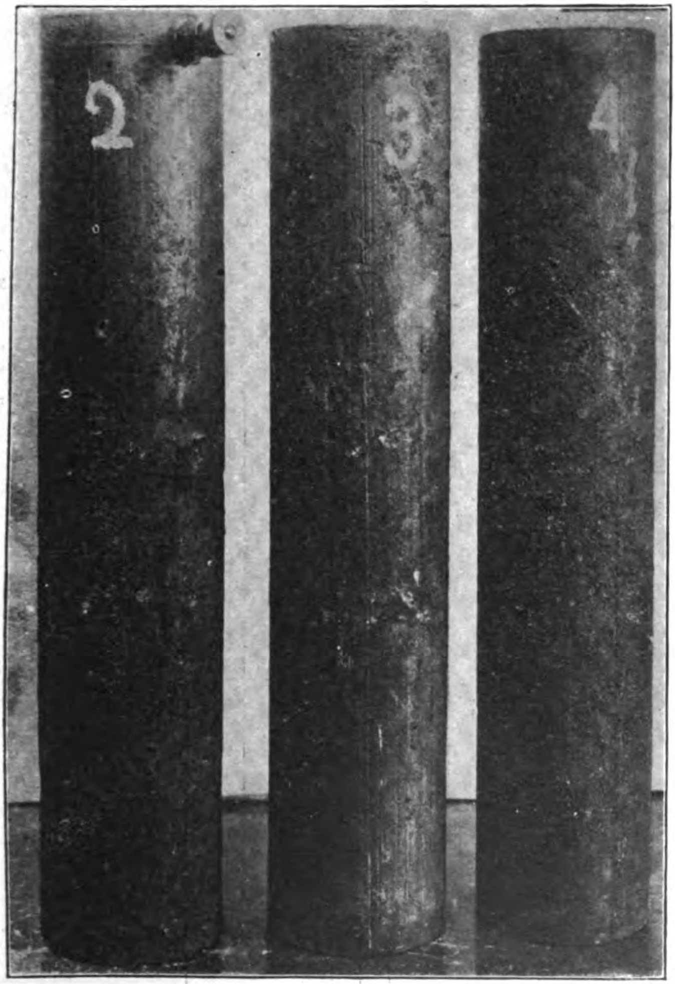
Sixth day of test. Cracks were observed in both samples of concrete, those in No. 5 being the most prominent. A small amount of water was found standing in the bottom of pipe No. 5. None in pipe No. 6.

Seventh day of test. The cracks in the concrete are increasing in the case of both samples.

Ninth day of test. A yellow frothy substance appeared at several points at the top of the concrete, close to the iron pipe of sample No. 6. Later this turned rust color.

Eleventh day of test. Same rust colored deposit observed around pipe of sample No. 5. The cracks of both samples have increased in prominence.

Eighteenth day of test. The cracks have assumed such proportions that it appears as though the concrete might easily fall apart, being $\frac{1}{8}$ to $\frac{3}{16}$ of an inch in many places. There is considerable rust colored, frothy deposit on top of sample No. 5, especially near the pipe.



(GROUP 1)
(1st series)

FIG. 5

It appears from these observations that before the ninth day, the process of electrolysis had arrived at quite an advanced stage on both blocks and before the rise in resistance took place, which afterwards in fresh water reached 300 to 400 ohms, requiring some 30 to 40 volts to maintain the 0.1 ampere. We should not, therefore, conclude that because such high readings are not found in practice, it is a sign that there can be no electrolysis. In the salt water block it is observed that even to the eleventh day of the test 5.5 volts only was required to pass the 0.1 ampere, and at that time the record states the cracks in both samples have increased in prominence.

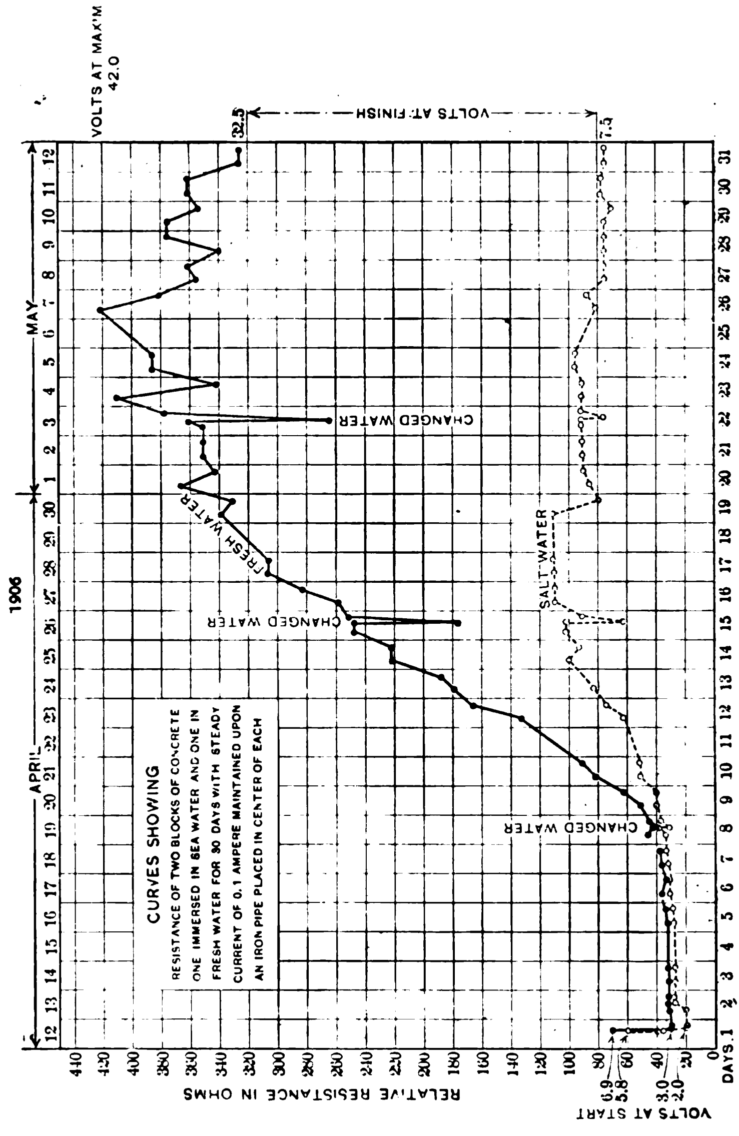


FIG. 6.

This report concludes as follows:

After the conclusion of the test which continued over thirty days, time, the concrete blocks were removed from the water and allowed to dry. They were then broken open. Block No. 5 which had been under test in the salt water was found to have a rust colored deposit extending along the sides of a crack from the external surface to the pipe, as shown by the accompanying photograph. The rust colored deposit in sample No. 6 was only about the pipe.

There were spots especially in the fresh water block No. 6 where the concrete had softened to such an extent as to be readily dug out with a knife.

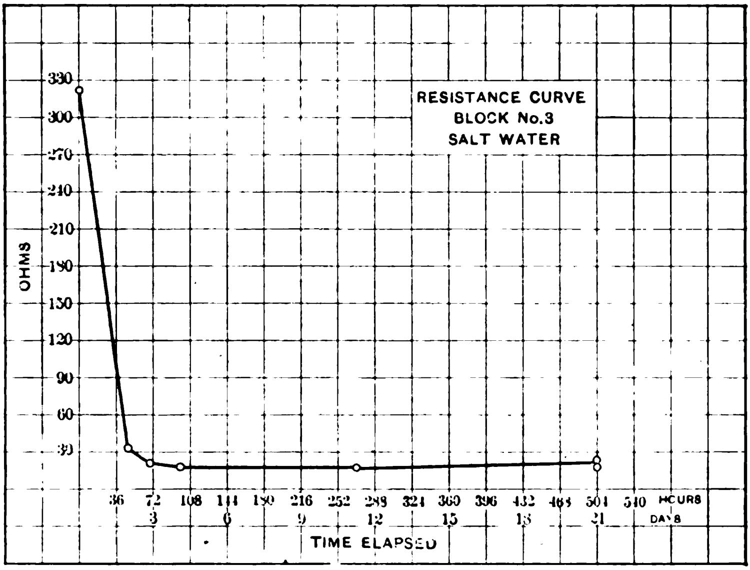


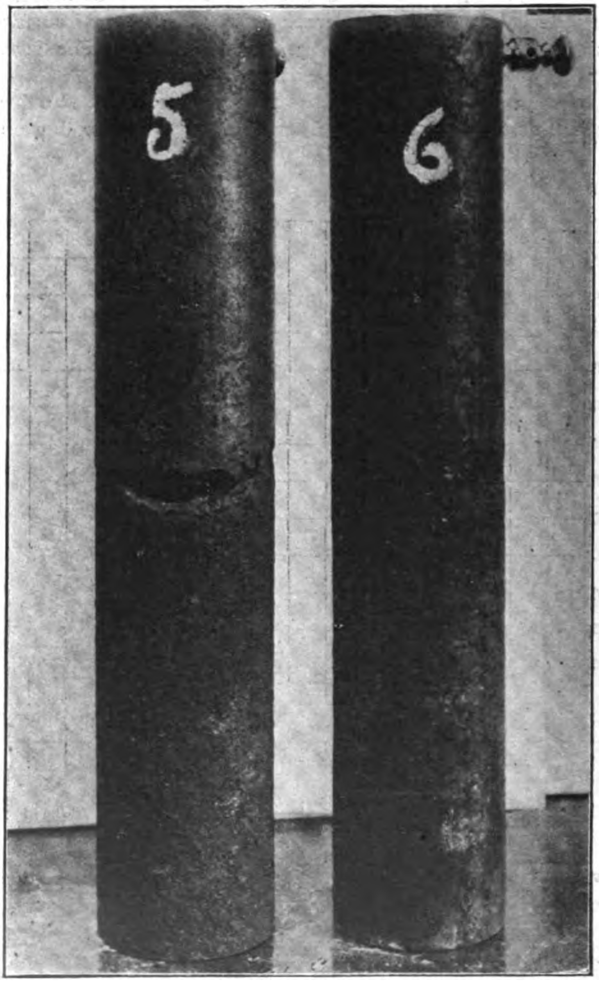
FIG. 7.

The weights of the pipe before and after the tests are given in the following table:

	No. 5 salt water.	*No. 6 fresh water.*
Initial	3 lb. 7.1 oz.	3 lb. 6.6 oz.
Final	3 5.5 "	3 5.5 "
Loss	1.6 oz.	1.1 oz.

Since the scale was not entirely removed for the final weighing, the loss in weight indicated does not represent the actual total amount of electrolysis which had occurred. However, all scale that could be readily removed was removed by Mr. Knudson before the final weights were taken.

This second series of tests show results very similar to the first, only more pronounced; and we believe they also show that the results would be practically the same with concrete made up with any of the different brands of cement found in the market, or made with different proportions of sand, or made of brick, or stone masonry.

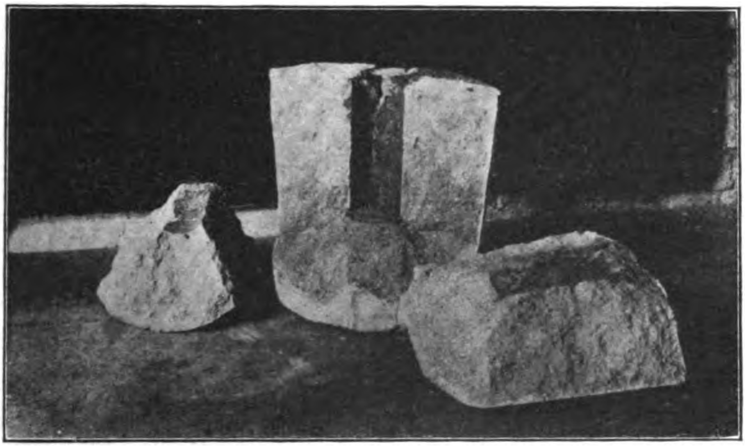


(Group 2)
(2d series)

Fig. 8.

The photographs of the different pipes show to some extent the effects of electrolytic action upon their surface which was in the concrete, except No. 3, Fig. 5, which had no current. No. 5, Fig. 8, which was in the salt water block, shows the most severe case, having a hole through the iron. This hole is one inch long and three eighths of an inch wide at its widest part, as genuine a case of electrolysis as any we have seen in larger pipes removed from a street.

Referring to the photographs of the blocks, all but No. 3 (which had no current) show the discoloration made by the iron rust extending in most cases through what were cracks to the outside surface. No. 3 shows a perfectly clean and hard interior surface. As the report states, there was no evidence of corrosion. It was like breaking open a piece of granite, and required the services of a "hard handed son of toil" with a sledge-hammer and chisel. The other blocks which were under test could be pried apart with an ordinary screw-driver inserted in the cracks.



(Block 5) FIG. 9.

Attention is called to block 5, Fig. 9 (sea water) where one of the cracks is shown at the back and about the center of the curve from which the iron tube was removed. The object of using sea water in our tests, as well as fresh water, was to ascertain and compare the resistances shown in the curve sheet, and also to conform as nearly as possible to conditions found in practice, such as bridge-piers and other structures that are located on water-fronts.

These tests and experiments go to show that only a small fraction of an ampere is necessary to cause electrolytic action. The element of time being always with us, it is only necessary where electric currents are present of sufficient voltage in the proper direction to cause even a very small amount of current to pass that will in time cause corrosion upon interior steel structures, whether placed in concrete, brick, or in granite masonry. It is not expected, however, that large granite piers would develop cracks, but electrolysis to interior steel work and to bridge anchorages may go on just the same. Cracks may develop, however, in concrete piers of small bridges, such as those which cross creeks or canals.

By way of a practical illustration, there is a bridge in this city of this description over the Gowanus Canal, South Brooklyn, at Hamilton Avenue. A portion of the Bridge Commissioner's report ending June 30, 1906, referring to this bridge, is as follows:

> HAMILTON AVENUE BRIDGE.
>
> Since construction, the foundation walls of this bridge have developed some rather serious cracks, occurring on both sides of the canal, and there has been a movement of the walls towards the centre of the canal. During the last three months this movement has amounted to half an inch. Previously the movement totaled about three and one-half inches. From October to March there was practically no movement. A continuation of this movement for several inches more will result in the necessity of alterations in the centre of the leaves, as they will interfere before the bridge can be fully closed.

With a view of ascertaining the electrical conditions, we have made a few tests at this bridge. The voltmeter readings show the steel structure to be positive to the canal, positive to water-mains in the street, and positive to the trolley-rails on the bridge, ranging from 0.5 to 1.5 volts. These readings were taken when the car-traffic was light. Some of the cracks on the concrete had been plastered over, but others were quite visible. The tests indicate that the trolley tracks on the bridge are in connection with the steel structure. Tests were also made on another bridge of the same construction a little further north over the same canal, at Ninth Street. The readings here were exactly the reverse to those found at the Hamilton Avenue Bridge, the structure being negative to canal, to water-mains and tracks. There were no visible cracks in the concrete of either foundation. Although the cracks in the concrete of the Hamilton Avenue Bridge are attributed to other causes in the Commissioner's report, we believe these tests and ob-

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servations point strongly to electrolytic action from trolley currents as being the true cause. This seems to us the more reasonable cause for these cracks, in view of the results of our laboratory experiments just described. Ordinary care would suggest that costly structures of this kind in this or other cities should be periodically inspected for evidence of electrolytic action upon the interior steel work, especially if located contiguous to water, or in the vicinity of electric railways or *railway power stations* as in the case just cited. Furthermore, this question should be carefully considered when such structures are planned, tests made at locations of proposed bridges or other structures, to ascertain the electrical conditions and the possibilities of injury due to electrolysis from stray currents.

This question of electrolytic corrosion of interior steel in the construction of high buildings, however, has not been entirely neglected. There is at least one case, that of the *New York Times* Building, where provision has been made in advance as a protection. In the Building Supplement, issued by that paper, dated January 1st, 1905, an interesting description is given in detail of the entire construction of that building. The following extract, referring to electrolysis, will be of interest:

> The danger that in the case of the steel frame, rust and the disintegration of electrolysis would hasten the process of dissolution so much as to make structures of this kind prematurely unsafe through the destruction of their supports, was recognized in time to permit of ample safeguarding in the case of the steel frame of the Times Building. It is axiomatic that columns to which moisture has no access will not be impaired by rusting, and that those effectually insulated from vagrant electrical currents will not be affected by electrolysis. The first consideration was to keep the basements dry. Hence the thorough waterproofing and draining of the retaining walls already described, which was carried under the floor of the press room, occupying the great area of the sub-basement. As a further safeguard, all the steel members up to the street level are incased in Portland cement mortar, to the minimum thickness of three-fourths of an inch. This is effectual protection against rust deterioration. Under these conditions electrolytic disintegration is deemed impossible, but the probability of its occurrence in even mocroscopic degree is rendered still further remote by as perfect insulation as can be provided. There is sufficient grounding to relieve any electrical tension which may exist in any part of the steel frame by drawing off the current at points where electrolytic action cannot be set up.

This is the first instance we have noticed where a large corporation has recognized this danger and has taken steps beforehand to avoid it. The protection of steel structures already constructed, however, is a different matter. While plans may be made to provide insulating methods and waterproofings, before construction, it is not easy to prevent corrosive action, when the conditions are favorable, after construction.

Another point which may have an important bearing on this subject, is the great pressure upon pillow-blocks, and upon piers supporting as they do enormous weights, which serve to make excellent electrical contact with concrete or masonry on which they stand, and, therefore, offer further opportunity for inviting stray currents.

Figs. 10 and 11 are photographs of the underside of two water meters which were practically destroyed by electrolysis while in service in the cellars of dwellings in a distant city. They were discovered during a survey by the writer in October last. They are shown as an illustration of how railway currents will follow a service pipe for a considerable distance from the tracks, enter a building, and find an outlet to ground on the damp soil of a cellar. This furnishes an opportunity for current to pass into the iron foundations of large buildings where such service pipes, either water or gas are connected, as they usually are, to the framework of such structures. These illustrations are by no means isolated cases. We have discovered many similar cases of current straying into buildings in different cities in this country. There were three meters found destroyed in this way in different sections of the city from which they were taken. They were from one to two miles apart. The distance from the tracks of Fig. 10 was

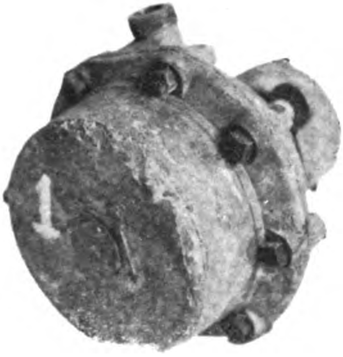

Fig. 10.—300 ft. from nearest track.

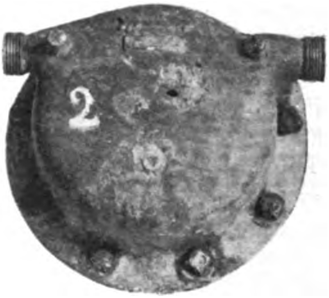

Fig. 11.—675 ft. from nearest track.

300 ft., and of Fig. 11, 675 ft. All of these meters were on side streets, at right angles to the car tracks.

IN REGARD TO REMEDIES

Coatings of various kinds of paints or varnishes will be of little use as an insulation, for it must be borne in mind that not only a moisture resistant is required, *but an insulation that will resist continual moisture*, and also that will stand the pressure of great weights.

From these laboratory experiments, as well as observations in practice, we draw the following conclusions.

1. Steel structures are well preserved from ordinary corrosion by concrete if placed either in salt or fresh water. This, however, has long been known.

2. If but a small fraction of an ampere of electricity passes from an interior metallic column or structure into concrete or masonry as usually made, there will be corrosion of the metal and disintegration of the concrete or masonry.

3. Structures of steel in concrete that are subject to sea water are in more danger from electrolytic action than those in fresh water, by reason of the lower resistance of concrete in sea water as shown by the laboratory experiments.

4. In no sense can concrete be considered an insulator, and as shown it is from all appearances, just as good an electrolyte as any of the soils found in the earth.

Other investigators in this field have given valuable information on this subject. Mr. Maximilian Toch, in a paper before the American Electrochemical Sciety in June last, gives an interesting account of some experiments conducted by himself with steel in concrete, and although on somewhat different lines to our own, arrives at practically the same results.

Mr. M. P. Wood, in his excellent work entitled "Rustless Coatings, Corrosion, and Electrolysis of Iron and Steel," refers to this subject as follows:

> It is a false reliance that masonry, mortar, concrete, or cement are impervious to moisture and incapable of acting as an electrolyte such as would induce electrolysis. They are not insulating substances, or at the best only in the smallest degree under the most favorable circumstances. They are positively porous and in nearly every case, whether tested in large or small mass, are permeable to all waters or moisture and gases, and in but a few exceptional cases ever become thoroughly dry.

It is therefore to be expected that so long as the single trolley with its grounded return is in general use, just so long may we look for electrolytic action in some form upon various underground structures; and reinforced concrete is no exception to the rule.

It is not at all surprising that such currents are busy at steel work of bridge-anchorages. Whether enclosed in concrete or masonry, these materials, as we have endeavored to show, are no protection from the straying railway current when the conditions are favorable for electrolytic action. In view, therefore, of these items presented, and the enormous use to which concrete and hydraulic cements are now put, it would seem that this question should receive due consideration by those who have to do with planning and constructing important public works and buildings, as well as those who are entrusted with the care and safety of such structures.

A paper presented at the 214th Meeting of the
American Institute of Electrical Engineers
New York, March 1, 1907.

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(Subject to final revision for the Transactions.

SOME THEORETICAL NOTES ON THE REDUCTION OF EARTH CURRENTS FROM ELECTRIC RAILWAY SYSTEMS BY MEANS OF NEGATIVE FEEDERS

BY GEORGE I. RHODES

The subject of earth currents caused by electric railway systems is of such importance that it is believed a few theoretical notes on the relative efficiencies of different return feeder systems in reducing stray currents will not be without interest.

Consider any system, the potential of whose running rails may be represented by the Curve *I*, Fig. 2, which is plotted with distances from the power house or sub-station as abscissas, and potentials of the rails referred to the negative bus-bar as ordinates. Assume for the time being that all resistance offered to current flowing from the tracks to earth is in the contact between rails and earth.

Let a = contact resistance per foot between rails and earth.
l = distance from power station.
v = potential of rails referred to negative bus-bar.
I_g = total leakage current.

Now if the negative bus-bar is completely grounded, and the earth of uniform potential, as would be the case if it had zero resistance,

$$\Delta I g = \frac{v \Delta l}{a}$$

$$I g = \sum \frac{v \Delta l}{a}$$

If a is uniform over the entire line, it is evident that the leakage current will be measured by the area enclosed between the potential curve of the track and the line of zero potential. If a is not uniform, the area will not be a true measure, but it will still be indicative of the amount of current flowing from the rails.

If now the negative bus-bar is insulated, the earth will have a potential with reference to the bus-bar such that the current flowing out of the rails shall be equal to that flowing into them. Under the assumption of uniform contact resistance between track and ground, this potential will be such that the areas enclosed by the potential curve, above and below the line of earth potential, are equal.

The assumption that the earth is of uniform potential is obviously far from correct, for since its resistance is not zero it is raised to a certain extent by the presence of a grounded conductor of higher potential. If the curve is plotted with reference to the ground in the vicinity of the rails as zero, the area enclosed by the curve will then measure the true leakage current with the above limitations; but if the curve is plotted with reference to the earth at that point where the rails and ground are at the same potential, the area enclosed will not measure the actual leakage, but rather the maximum current that would flow if the earth offered no resistance except at the surface of contact with the rails.

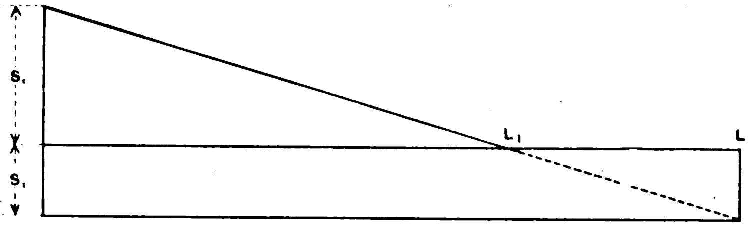

Fig. 1.—Distribution of copper for uniform drop.

On this latter assumption, then, the following cases will be considered, both with the negative bus-bar thoroughly grounded and insulated. The load is considered to be uniformly distributed over the whole line, which extends in one direction only from the power station.

I. No copper in return circuit.

II. Copper of uniform section bonded to the rails at short intervals.

III. Copper distributed to give uniform drop, bonded to the rails at short intervals.

IV. A single insulated negative feeder connected to rails at middle of the line, and at the power station.

V. A single insulated feeder connecting the rails to the negative bus-bar only at the middle of the line.

VI. Several insulated feeders.

VII. Several insulated feeders with equal potentials at all feed points.

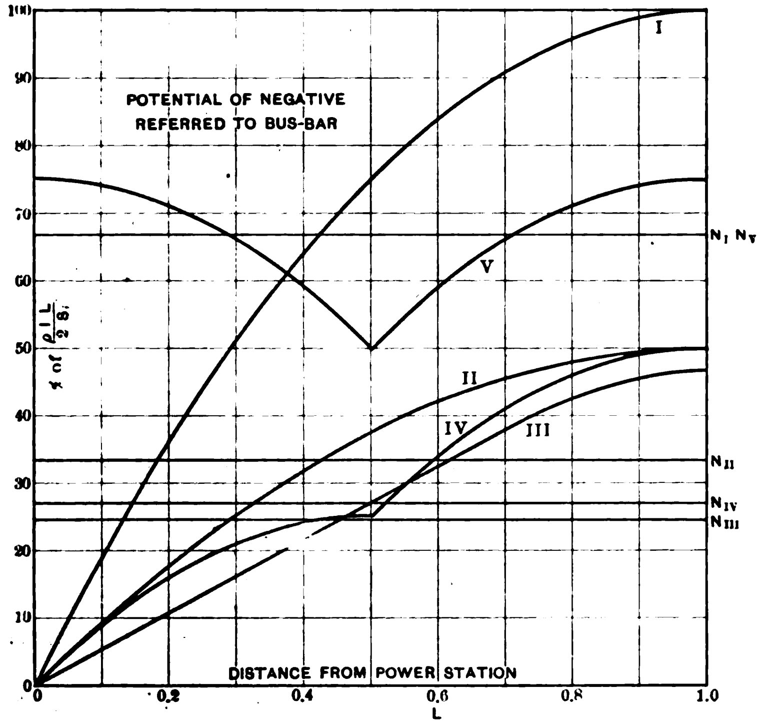

Fig. 2.

The following notation will be used:

i = current at any point on line.

I = total current.

v = potential at any point referred to bus-bar as zero.

l = distance from power station.

L = total length of line.

r = resistance per foot of return.

ρ = 10.30^{ω} = resistance per cir. mil-foot of copper.

ω = 0.00,000,302 lb. = weight per cir. mil-foot of copper.
s_i = equivalent conductivity of track rails in cir. mils of copper
s_c = cir. mils of return copper at power station.
W = weight of return copper.
A = area representing leakage current with negative bus-bar grounded.
a = area representing leakage current with negative bus-bar insulated.

I. No return copper.

$$i = I\left(1 - \frac{l}{L}\right)$$

$$r = \frac{\rho}{s_i}$$

$$V = \int i\, r\, d\, l = \frac{\rho I}{s_i}\left(l - \frac{l^2}{2L}\right)$$

The curve represented by this equation and shown as I in Fig. 2, is a parabola whose axis is parallel to the axis of v and whose apex is at the point

$$l = L \quad v = \frac{\rho I L}{2\, s_i}$$

With the bus-bar grounded, the area beneath the curve measures the leakage current, and is,

$$A = \frac{\rho I L^2}{3\, s_i}$$

as obtained by means of the usual formula giving the area enclosed by a parabola.

With the bus-bar insulated, it can be shown by equating the areas enclosed by the curve above and below the neutral line that the earth and rail are at the same potential at the point

$$L_0 = L\left(1 - \frac{1}{\sqrt{3}}\right)$$

and the area representing leakage current is

$$a = \frac{1}{3\sqrt{3}} \quad \frac{\rho I L^2}{3\, s_i}$$

II. Return copper of uniform section.

$$i = I\left(1-\frac{l}{L}\right) \text{ as before}$$

$$r = \frac{\rho}{s_i+s_c}$$

$$v = \frac{\rho\, I}{s_i+s_c}\left(l-\frac{l^2}{2\,L}\right)$$

The curve representing this equation when $s_c = s_i$ is shown as Curve D, Fig. 2. It is a parabola as in Case I, but its ordinates bear the ratio $\frac{s_i}{s_i+s_c}$ to those of the first curve.

The area representing leakage current with grounded bus-bar can be shown to be

$$A = \frac{s_i}{s_i+s_c}\;\frac{\rho\, I\, L^2}{3\, s_i}$$

and with the bus-bar insulated the neutral is at

$$L_0 = L\left(1-\frac{1}{\sqrt{3}}\right)$$

making

$$a = \frac{s_i}{3\sqrt{3}\,(s_i+s_c)}\quad\frac{\rho\, I\, L^2}{3\, s_i}$$

The weight of copper is

$$W = \omega\, s_c\, L$$

III. Copper distributed for uniform drop.

$$i = I\left(1-\frac{l}{L}\right) \text{ as before}$$

$$r = \frac{\rho}{(s_i+s_c)\left(1-\frac{l}{L}\right)}$$

That is, the conductivity is proportional to the current.

$$v = \frac{\rho I l}{s_i + s_c} \text{ a straight line.}$$

It is evident that this equation can hold only when l is such that

$$(s_i + s_c)\left(1 - \frac{l}{L}\right) = s_i$$

ther. $$l = L_1 = L\frac{s_c}{s_i + s_c}$$

For values of $l > L_1$, the conductivity is uniform and equal to that of the rail return (see Fig. 1).

From $l = L_1$ to $l = L$

$$i = \frac{L_1 I}{L} - \frac{l}{L}$$

$$r = \frac{l}{s_i}$$

$$v = \frac{\rho I}{s_i}\left[\frac{L_1(l - L_1)}{L} - \frac{(l - L_1)^2}{2L}\right] + \frac{\rho I L_1}{s_i + s_c}$$

This curve is that portion of the parabola I, Fig. 2, beyond $l = L_1$, dropped until it is tangent to the straight line.

$$v = \frac{\rho I l}{s_i + s_c}. \quad \text{See III, Fig. 2.}$$

The area representing leakage current with the bus-bar grounded can be shown to be

$$A = \frac{s_i(3s_c^2 + 6s_i s_c + 2s_i^2)}{2(s_i + s_c)^3} \cdot \frac{\rho I L^2}{3 s_i}$$

and with the bus-bar insulated the neutral point is at

$$L_0 = \frac{L}{2}\left\{1 - \frac{s_i^2}{3(s_i + s_c)}\right\}$$

for values of $s_c > 0.815\, s_i$

This makes

$$a = \frac{s_i(3s_c^2 + 6s_i s_c + 2s_i^2)^2}{24(s_i + s_c)^5} \cdot \frac{\rho I L^2}{3 s_i}$$

The weight of copper used is

$$W = \omega s_c \frac{L_1}{2} = \frac{\omega s_c^2 L}{2 (s_i + s_c)}$$

In order to compare properly this case with Case II, equal amounts of copper must be used making

$$\frac{s_{c_{iii}}^2}{2 (s_i + s_{c_{iii}})} = s_{c_{ii}}$$

$$s_{c_{iii}} = s_{c_{ii}} + \sqrt{s_{c_{ii}}^2 + 2 s_i s_{c_{ii}}}$$

IV. Single insulated return feeder from middle of line. Connection to rails at power house.

By the use of Kirchoff's laws it can be shown that

From $l = o$ to $l = \frac{L}{2}$

$$i = I \left(1 - \frac{3 s_c}{4 (s_i + s_c)}\right) - I \frac{l}{L}$$

$$r = \frac{\rho}{s_i}$$

$$v = \frac{\rho I}{s_i} \left\{ l \left(1 - \frac{3 s_c}{4 (s_i + s_c)}\right) - \frac{l^2}{2 L} \right\}$$

From $l = \frac{L}{2}$ to $l = L$

$$i = \frac{I}{2} - I \left(e - \frac{L}{2}\right)$$

$$v = \frac{\rho I}{s_i} \left\{ \frac{\left(l - \frac{L}{2}\right)}{2} - \frac{\left(l - \frac{L}{2}\right)^2}{2 L} + \frac{L}{2} \left(\frac{3 s_i}{4 (s_i + s_c)}\right) \right\}$$

Both curves are portions of the parabola of Case I (see IV, **Fig. 2**).

The area representing leakage current can be shown to be

$$A = \left\{ 1 - \frac{27 s_c}{32 (s_i + s_c)} \right\} \frac{\rho I L^2}{3 s_i}$$

and with the bus-bar insulated

$$L_0 = L \left\{ 1 - \frac{1}{\sqrt{3}} \sqrt{1 - \frac{9\, s_c}{16\,(s_i + s_c)}} \right\}$$

making $$a = \frac{1}{3\sqrt{3}} \left(1 - \frac{9\, s_c}{16\,(s_i + s_c)}\right)^{\frac{3}{2}} \frac{\rho\, I\, L^2}{3\, s_i}$$

The weight of copper used is

$$W = \frac{\omega\, s_c\, L}{2}$$

Making for proper comparison with Cases II and III

$$s_{i_{iv}} = 2\, s_{c_{ii}}$$

V. A single insulated return feeder from middle of line. No other connection to rail.

It can be shown that from $l = o$ to $l = \frac{L}{2}$

$$i = - \frac{l\, I}{L}$$

$$v = \rho\, I\, L \left[\frac{1}{2\, s_c} + \frac{1}{8\, s_i}\right] - \frac{\rho\, I\, l^2}{2\, s_i}$$

and from $$l = \frac{L}{2} \text{ to } l = L .$$

$$i = \frac{I}{2} - \frac{I}{L}\left(\rho - \frac{L}{2}\right)$$

$$v = \frac{\rho^{I}}{s_i} \left\{ \frac{\left(\rho - \frac{L}{2}\right)}{2} - \frac{\left(\rho - \frac{L}{2}\right)^2}{2\,L} + \frac{L\, s_i}{2\, s_c} \right\}$$

These are two symmetrical portions of the parabola of Case I intersecting at the point $l = \frac{L}{2}$ $v = \frac{\rho\, I\, L}{2\, s_c}$ (see V, Fig. 2).

With the bus-bar grounded the area representing leakage current is

$$A = \frac{6\,s_i + s_c}{4\,s_c} \cdot \frac{\rho\, I\, L^2}{3\,s_i}$$

and with the bus-bar insulated there are two neutral points at

$$L_0 = \frac{L}{2\sqrt{3}} \text{ and } L_0 = \frac{L}{2}\left[1 - \frac{1}{\sqrt{3}}\right]$$

making $$a = \frac{1}{12\sqrt{3}} \frac{\rho\, I\, L^2}{3\,s_i}$$

The weight of copper is the same as in Case IV.

VI. With several insulated feeders the potential curve will take a form similar to that of Case V in which the curve between any two feeders is a portion of the parabola of Case I. If the feeders are of uniform size, the general form of the potential curve will approach the straight line of Case III as numbers of feeders is increased indefinitely. With a single feeder the area measuring leakage current is larger than for the case with the copper distributed for uniform drop, and with increasing number of feeders this area will approach it as a limit, being always larger.

With feeders graded in size to give uniform potential at the feed points the curves will be of the forms in Case VII.

VII. Several insulated feeders with equal potentials at feed points.

In this case the uniformly equal potentials at the ends of feeders may be secured by properly adjusting the sizes or by means of negative boosters. By adjustment of sizes, the potential of the track must necessarily be greater than that of the bus-bar, and if there is a solid ground at the power station there will be a leakage current due to this difference; but with the use of boosters the potentials at the ends of the feeders can be maintained at uniform with the negative bus-bar, and furthermore, this, with a widely fluctuating load such as is the case on an electric railway.

For the best results with a given number of feeders it is evident that they must be connected to the rails at such points as will give equal maxima on the potential curves. This may be accomplished in two ways, viz.:

1. No connection to rails at power station, and distance between feed points twice the distance from the power house to the first point, and from the last point to the end of the line. (See Fig. 3.)

2. Connection to rails at power house with the distance between feed points, and from the power station to the first feed point equal to twice the distance from the last point to the end of the line. (See Fig. 4.)

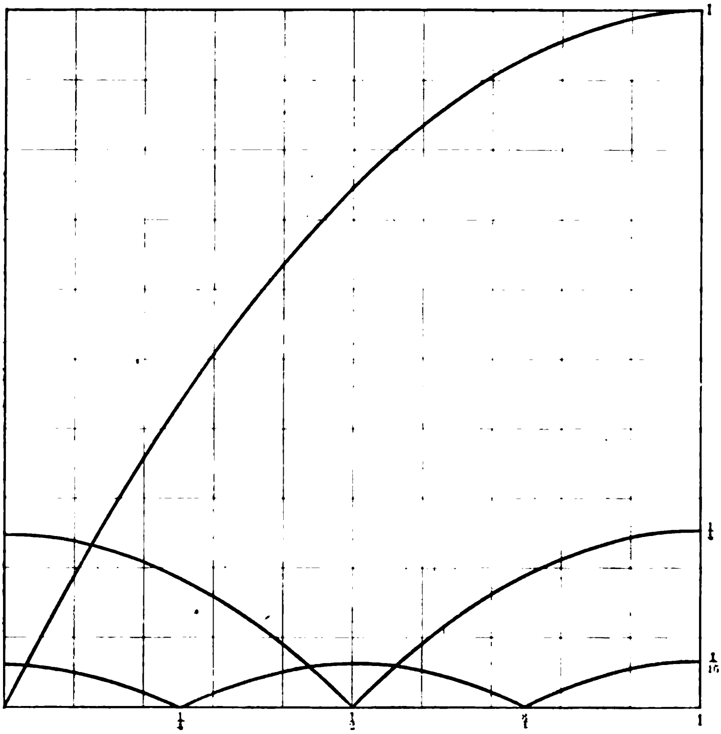

FIG. 3.—Potential of negative referred to bus-bar.—Case VII.

1. With a single feeder and no connection at power house, the feed point for equal maxima will be at the centre of the line. (See Fig. 3.) the potential curve being made up of the upper portions of the parabola of Case I, also shown in Fig. 3.

With the bus-bar grounded the area beneath this curve is

$$A = 2 \times \tfrac{2}{3} \times \frac{L}{2} \times \tfrac{1}{4}\,\frac{\rho\, I\, L}{2\, s_1} = \tfrac{1}{4}\,\frac{\rho\, I\, L^2}{3\, s_1}$$

With two feeders the feed points will be ¼ and ¾ of the distance from the power house and the area will be

$$A = 4 \times \tfrac{2}{3} \times \frac{L}{4} \times \tfrac{1}{16} \times \frac{\rho I L}{2\, s_i} = \tfrac{1}{16}\, \frac{\rho I L^2}{3\, s_i}$$

With μ feeders the feed points will be at

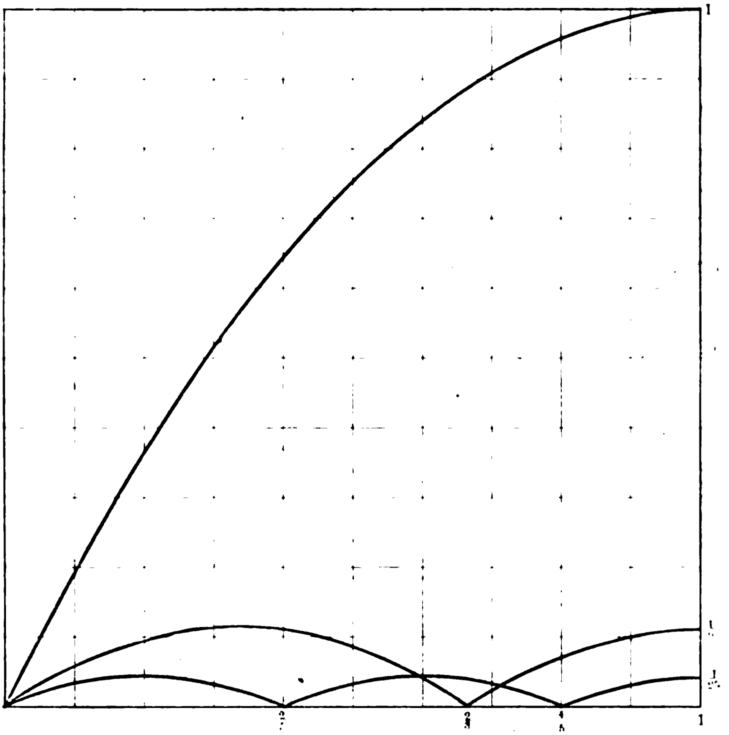

Fig. 4.—Potential of negative referred to bus-bar.—Case VII.

$$\frac{1}{2\,\mu},\ \frac{3}{2\,\mu} \cdots \frac{2\,\mu - 1}{2\,\mu}$$

of the distance from the power house to the end of the line, making

$$A = 2\,\mu \times \tfrac{2}{3} \times \frac{L}{2\,\mu} \times \frac{1}{(2\,\mu)^2} \times \frac{\rho I L}{2\, s_1} = \frac{1}{4\,\mu^2}\, \frac{\rho I L^2}{3\, s_i}$$

2. With one feeder the point of connection to the rails will be at $l = \frac{2}{3} L$, making

$$A = 3 \times \tfrac{2}{3} \times \frac{L}{3} \times \frac{1}{(3)^2} \times \frac{\rho I L}{2 s_i} = \frac{1}{9} \frac{\rho I L^2}{3 s_i}$$

With two feeders the points of connection will be at $l = \frac{2}{5} L$, and L, making

$$A = 5 \times \tfrac{2}{3} \times \frac{L}{5} \times \frac{1}{(5)^2} \times \frac{\rho I L}{2 s_i} = \frac{1}{25} \frac{\rho I L^2}{3 s_i}$$

With μ feeders the feed points will be at

$$l = \frac{2}{2 \mu + 1} L, \quad \frac{4}{2 \mu + 1} L \ldots \frac{2 \mu}{2 \mu + 1}$$

making

$$A = (2 \mu + 1) \times \tfrac{2}{3} \times \frac{L}{(2 \mu + 1)} \times \frac{1}{(2 \mu + 1)^2} \frac{\rho I L}{2 s_i} = \frac{1}{(2 \mu + 1)^2} \frac{\rho I L^2}{3 s_i}$$

$$= \frac{1}{4 \, (\mu + \frac{1}{2})^2} \frac{\rho I L^2}{3 s_i}$$

Thus it is evident that making a connection to the bus-bar in addition to using feeders has the effect in the equation

$$A = \frac{1}{4 \mu^2} \frac{\rho I L^2}{3 s_i}$$

of increasing the number by ½ a feeder. This will explain the points as the curve in Fig. 8 of ½, 1½, 2½ feeders, etc.

If the bus-bar is insulated the equation for area representing leakage current is

$$a = \frac{1}{12 \sqrt{3} \, \mu^2} \frac{\rho I L^2}{3 s_i}$$

In the case of insulated feeders with negative boosters the leakage current from rails to ground is entirely independent of the amount of copper used, and the size of feeders is determined solely by the cost of power necessary to run the boosters.

Having now found equations representing the leakage currents for the different cases, let us now compare them. Fig. 5 gives the cross-section of the copper at the power station in the several cases, to give equal weights of copper, the unit of weight

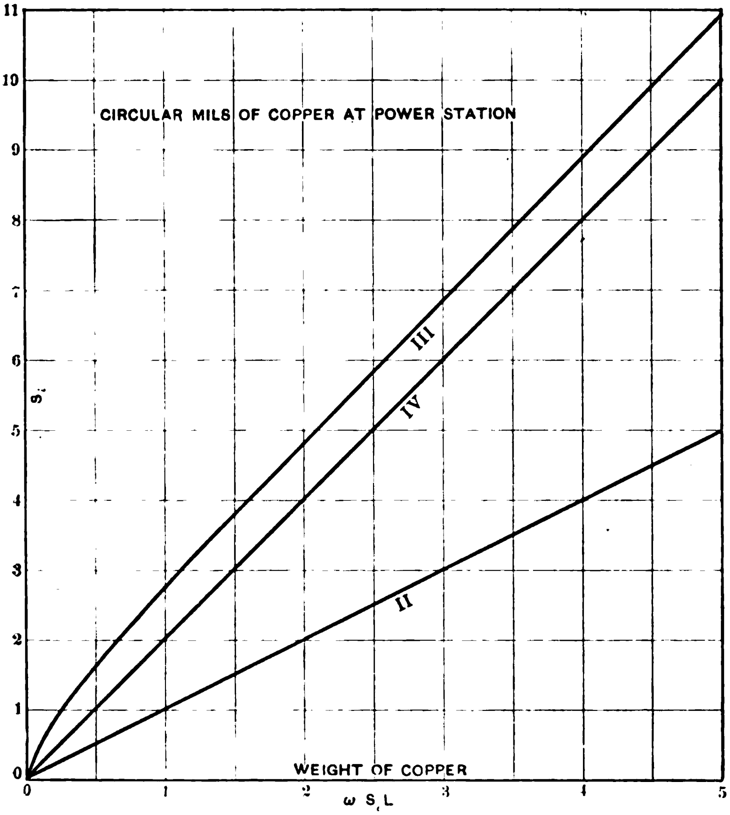

FIG. 5.

being $\omega\ s_i\ L$, or a weight of copper of length L which gives a conductivity equal to that of the rails.

Fig. 6 gives the relative leakage currents for the several cases (in which the bus-bar is grounded) plotted to amount of copper used. The unit of leakage current is taken as that which occurs on a line without negative copper in which the bus-bar is grounded.

Fig. 7 gives the relative leakage currents with the bus-bar insulated.

Fig. 8 gives the relative leakage currents for Case VII with bus-bars insulated, plotted with the number of feeders as abscissas, the points representing half feeders being as explained above.

It is at once apparent that insulating the negative bus-bar very much decreases the leakage current in all cases, the decrease being in the neighborhood of 80%. Further than this, it is unnecessary to consider the case of a solid ground at the power station. With the bus-bar insulated, it is seen that the leakage currents with the copper either uniformly distributed or distributed for uniform drop, are identical. The equations do not represent the same line but they coincide so nearly that the curves are identical within a very few per cent.

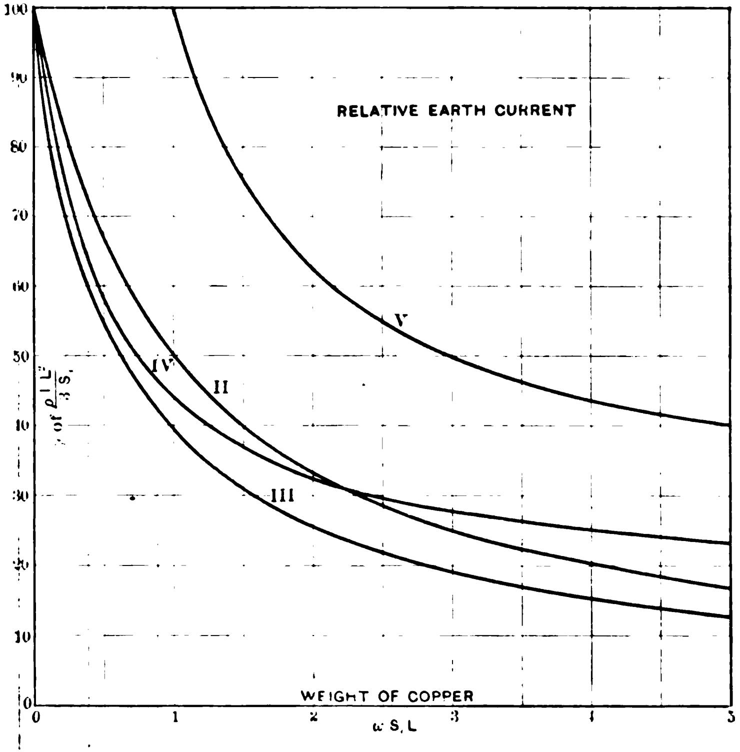

FIG. 6.

With a single feeder to the middle of the line and a connection to the bus-bar at the power station, it is seen that the results are poorer than for any other method for large feeders; the divergency becoming greater as the amount of copper is increased, but with a single feeder and no other connection between bus-bar or rails, the leakage is independent of the amount of copper used and equal to 4.8% of the original leakage with the bus grounded and no copper in the negative circuit.

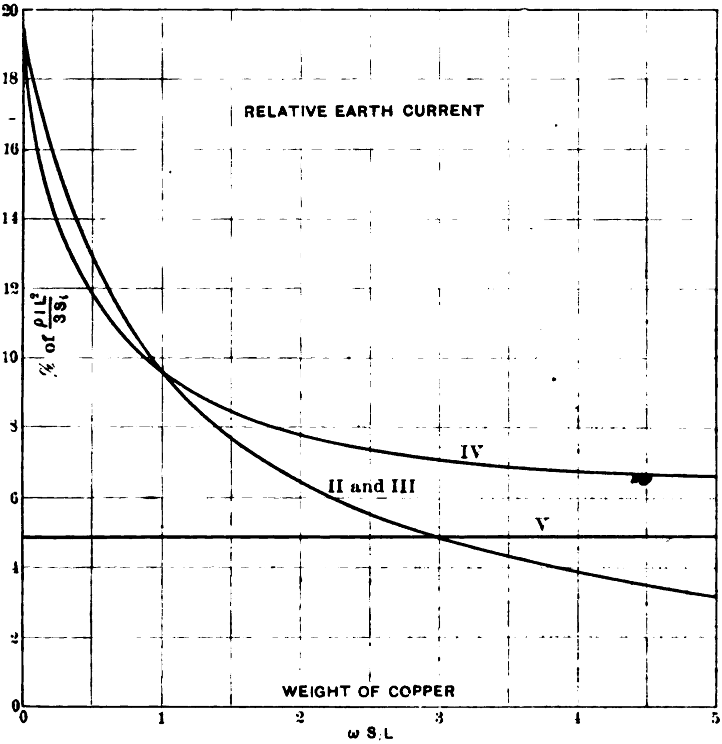

Fig. 7.—Relative earth current. Negative bus-bar insulated.

This latter is really covered by Case VII. The great superiority of the boosted negative feeder method of reducing leakage from the rails is at once apparent, two feeders reducing the leakage to 1.2% of its original value with the bus-bar grounded, or about 6.2% of its original value with the bus-bar insulated. Very little is gained by using more than two feeders.

In conclusion, a few figures as to the amount of copper required to reduce the leakage to one half with the bus grounded may be of interest. Let us consider a double-track road with 100-lb. rails. The equivalent conductivity of each rail is about 1,200,000 cir. mils of copper if well bonded, making $s_i = 4,800,000$.

If the copper is to be of uniform section, 4,800,000 cir. mils must be used the entire length of the line.

If the copper is to be distributed to best advantage it must be of a section 9,120,000 cir. mils at the power station, being reduced uniformly to zero at a point 65.5% of the distance to the end of the line. The total amount of copper used will be 62% of that in the first case.

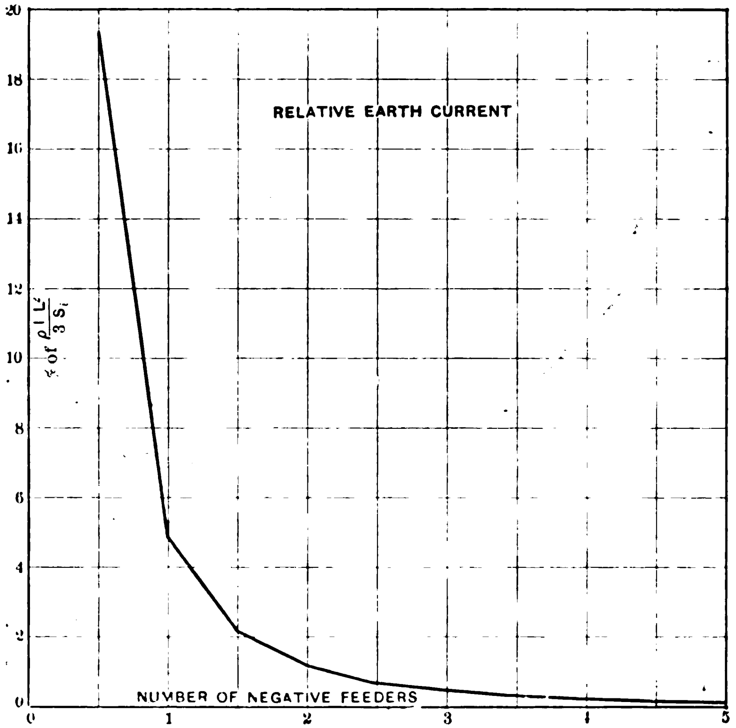

FIG. 8.—Relative earth current. Bus-bar insulated.—Case VII.

If an insulated feeder to the centre of the line is used, with a connection at the power house it must be of a section 7,200,000 cir. mils making the weight of copper 75% of that in the first case.

If the bus-bar is now insulated the 4,800,000 cir. mils of copper extending the entire length of the line will reduce the leakage to 9.7%; 62% of this copper distributed to best advantage will reduce the leakage to 12%; while a single feeder with a connection at the power house, using 75% of the copper will reduce it to 10.4%. Using a weight of copper determined only by its carrying capacity and the cost of power, in two boosted feeders, will reduce the leakage to 1.2% with no connection at the power house and by using 20% larger feeders, to 0.77% with such a connection.

A paper presented at a Meeting of the University of Wisconsin Branch of the American Institute of Electrical Engineers, Madison, Wis., December 20, 1906.

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(*Subject to final revision for the Transactions*)

HIGH-TENSION OUTLETS.

BY ALVIN MEYERS.

The building outlet in high-tension work has become very important and will increase in importance as higher pressures are used. A great variety of outlet arrangements have been tried, each company having a method of its own. Each arrangement has its disadvantages and all are liable to give serious trouble in case of storms. Blowing rain and snow will enter the building with the open outlet, while with the bushing it is found impractical to build with glass or porcelain to sufficient size to obtain the necessary surface resistance. Plate glass with holes through the center for the wires, which are supported on line insulators, has proved a serious menace, owing to the leakage setting fire to timber construction, and the formation of an arc in metal construction.

Inferior designs of outlets have often given fairly good satisfaction, due chiefly to local storm conditions. It is not extremely difficult to provide ample insulation as long as this insulation can be kept thoroughly dry, but when exposed to driving rain and sleet defects appear very quickly. In all cases the outlet insulation should be better than that of the line itself, owing to electrical storms which are otherwise liable to start a disastrous arc at the outlet end of the building.

The early outlets of the Telluride Power Company were of two types—the voltage on the system being 44,000 between lines on a star-connected bank of transformers with the star grounded—the first type, see Figs. 1 and 2, employed at the power house at Nunns, Utah, consisted of a 4 in. by 4 in. oak timber about 5 ft. long with a 1-in. hole bored through the center to carry the wire which was incased in a hard-rubber tube.

The oak was very carefully paraffined, and then passed through a tight-fitting hole in the wooden gable of the power house. On the outside each bushing was further protected by a hood. All of the high-tension gable and the hoods were built with care from seasoned timber, and coated with shellac and varnish. These outlets have given some trouble in the case of a driving storm of snow and sleet from the direction favorable to the wetting of the whole gable-end of the power house.

The second type of outlet was constructed in about the same way, except that the oak bushing was omitted and the line carried through an opening underneath the hood. In this case, snow blowing into the building was probably responsible for arcing over the transformer bushings.

In 1903 a series of tests were made at the Telluride Power Company's laboratory in Provo Canyon, on what was then a new insulating material called fibre conduit. This material is intended for use as underground conduit. It is manufactured in tubes of varying diameters, and in uniform lengths of 5 ft. each, the walls being from ¼ to ½ inch thick. These tubes secure their mechanical rigidity and insulating properties from a fibrous body treated with an asphaltum compound.

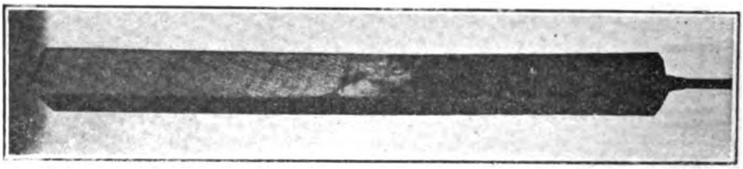

Fig. 1.

The results of the tests were as follows:

Walls ¼ in. thick punctures at 34,000 to 36,000 volts.
" ⅜ " " " " 49,000 " 57,000 "

No appreciable deterioration could be detected when the potential was maintained near the breakdown point for 10 hours.

The arc at first seems very loath to hold near the surface of a dry conduit; but after a continued test with constant leakage the arc finally starts and carbonizes a channel when it will hold along the surface. An arc sufficiently violent to carbonize the dry surface causes the material to burn with very little flame, which goes out almost instantly when the current is turned off. *Wet* surfaces deteriorate very rapidly, burning and carbonizing over almost the entire surface. This burning is plainly visible some time before actual breakdown occurs, and begins at a point so low as compared with dry surface tests that it was difficult to make any comparison, especially as the amount of moisture and the rapidity with which the test piece dried off after being soaked, was quite variable.

A bushing was next built up, as shown in Fig. 3. This bushing was built of three straight lengths of fibre conduit. $1\frac{1}{2}$-in., $2\frac{1}{2}$-in., and 4-in. tubes being placed concentrically, the spaces being filled with ozokerite. The outer end consisted of a 4-in. *T*-joint capped on the upper end and fitted with a 6-in. nipple on the lower end; this latter serving as a petticoat. A rubber-covered No. 8 flexible lead through the bushing was made one terminal of the transformer, the other terminal was

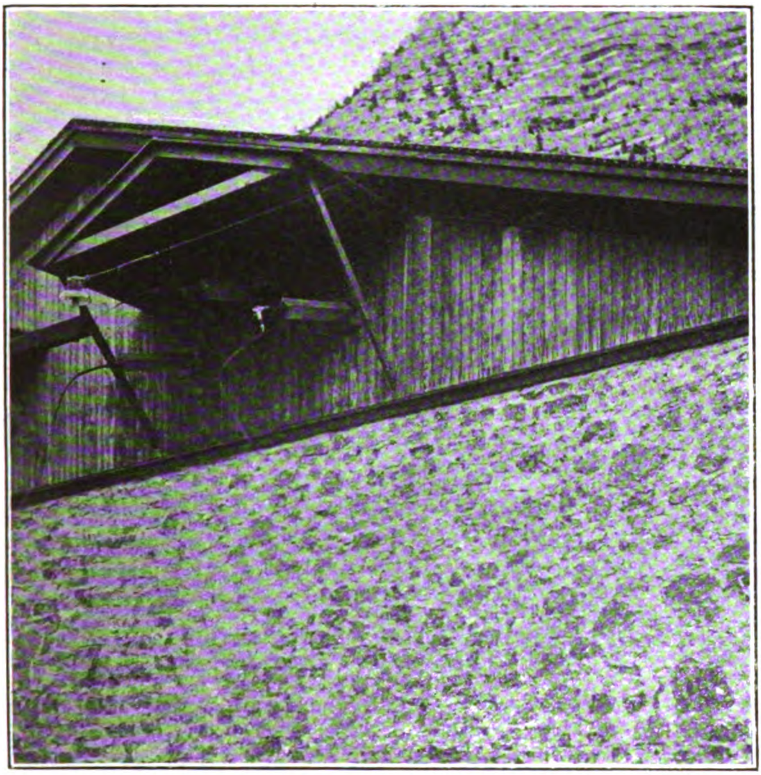

FIG. 2.

wrapped around the bushing at approximately what would be the wall position for such bushing. With this arrangement, 64,000 volts and upwards was applied for over five days, and although there appeared to be considerable radiation from the wires no surface leakage could be detected. Later the voltage was raised to 110,000 when light arcs and streamers over the end of the bushing inside of the transformer house indicated that the limit of surface resistance was reached, but no burning or puncture was obtained.

For the purpose of making the wet test, a hose with river water was set playing against the gable of the transformer house above the bushing. This threw a heavy spray over that part of the bushing outside the transformer house. First, the hose was left playing for two hours; then the pressure was raised in about 5 seconds from 0 to 48,000 volts when a heavy arc formed across the 4-in. air-gap at the end of the bushing, thence along the surface to the wire wrapping. The pressure was instantly taken off and after drying for 10 to 15 minutes (the atmosphere was very dry with some wind) the pressure was again applied without the hose being turned on, and the bushing stood up

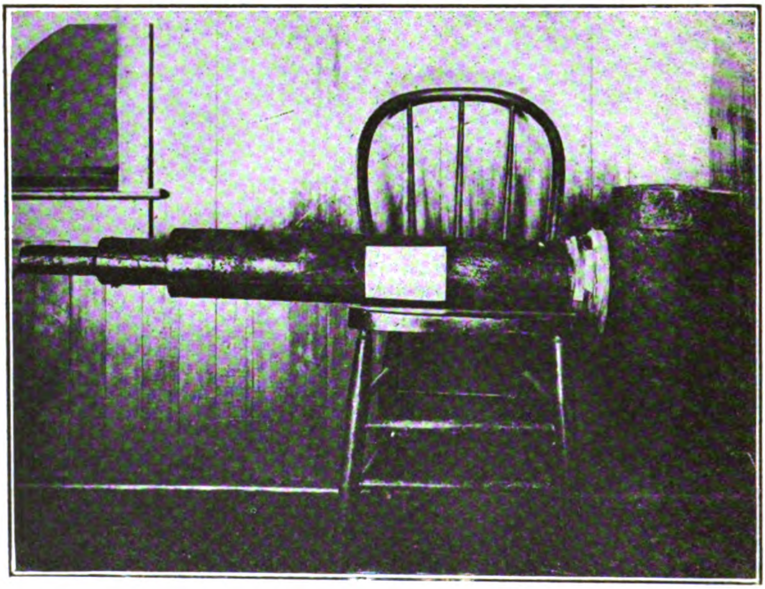

FIG. 3.

under 64,000 volts. An examination showed no appreciable carbonization. Next the hose was started again and the pressure raised more gradually with readings of voltmeter and wattmeter taken on the low-tension side. Excessive burning over the bushing surface became visible at 30,500 volts, but the wattmeter reading showed excessive loss starting at 22,000 to 23,000 volts. Finally the bushing was severely burned on the surface by allowing a heavy arc to hold for several minutes while the hose was playing. This caused a carbonized channel to be formed about 2 ft. in length along a rather erratic path, not zigzag, but not the shortest path. The channel was about $\frac{1}{16}$ in. deep. All this carbonized material was carefully scraped off and the dry test was repeated with approximately the same results as before. The bushing was left in place during the progress of some other tests, and has since been subjected to an actual storm test of wet snow and snow and rain mixed, with considerable wind, lasting for about 48 hours.

An actual storm test confirms the test with hose and spray of river water, and the wet tests as a whole show that the surface resistance of the conduit may be reduced 80% by wetting, while the puncture test remains practically the same with dry as with wet surface. A dry surface test compares favorably with a dry surface test on insulator glass. The puncture test shows excellent insulating qualities.

From the tests it will be seen that this material had properties that made it, when exposed to the weather, an unsuitable material; that is, its surface insulation when wet was very poor, while its dry surface and puncturing resistances were very good. Numerous varnishes and like materials were used in the endeavor to protect the exposed surface, but without results of sufficient value to warrant the use of this bushing exposed to weather conditions.

In the design of the Olmsted power house outlets, see Fig. 4, it was decided to make use of the fibre conduit with the ozokerite filling, in fact the bushings were filled with various materials, crude ozokerite being the chief substance used, while the ends were sealed with small quantities of a firmer compound. Chatterton compound, minerallac, and a very brittle asphaltum compound were used for sealing. These were used to prevent the oozing out of the material when subjected to the heat of the sun in summer. The Chatterton compound has proved to be less firm than the ozokerite and has oozed out slightly.

In order that the exterior surface of these bushings might be kept dry, a sheet-iron hood was designed to protect them from storms, see Fig. 5. The bushings were made of considerable length in order to decrease the surface leakage.

The conductor in these bushings is of 60,000-volt varnished cambric and braid insulation just large enough to fill tightly the 1½ in. inner tube of fibre conduit. These bushings have proved quite satisfactory, but it must be noted that the hood provides excellent protection against storms.

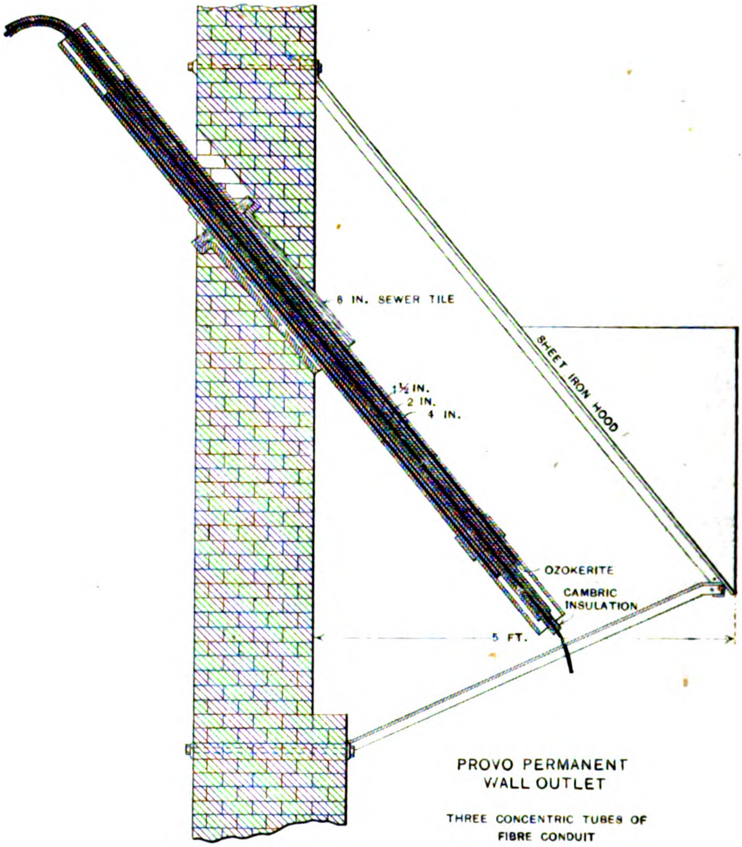

Fig. 4.

Tests on the 1.5 in. conduit with the insulated conductor alone gave a breakdown by puncture at 112,000 volts at the end of one minute's application.

Later in the spring of 1905, a switching station near Lehi, Utah, was equipped with approximately the same style of bushing, 40,000-volt insulated wire being substituted for the 60,000-wire mentioned above. It was thought that a liberal roof projection on the building would protect the surface of these bushings and they were set in the wall in a much more nearly horizontal position than at Olmsted.

These bushings had been installed but a short time when a driving rain storm accompanied by lightning practically destroyed the whole nine of these bushings. Several were punctured and the rest were severely burned over the entire surface. The building was only saved from fire by the presence of an attendant. The system was completely shut down until the attendant could cut the lines free from the building. This switching station is located in an unprotected place, where it is subject to the full force of storms as they come across Utah Lake.

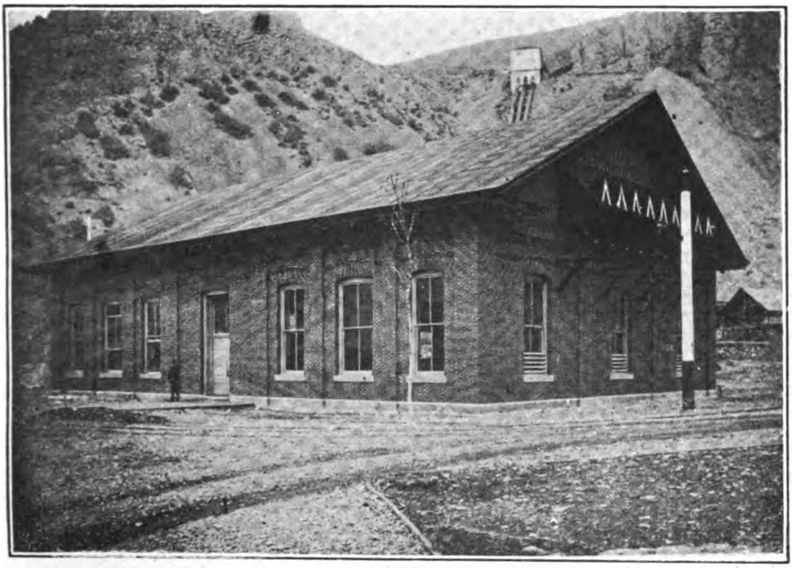

FIG. 5 —Power House at Olmsted, Utah.
10,000 h.p. capacity; line pressure 44,000 volts.

In consideration of the necessity of further protecting bushings of this kind from surface breakdown a porcelain collar was designed to screw on to the threaded end of the 4-in. conduit. See Fig. 6. Before screwing this collar on to the conduit, hot ozokerite wax was poured over the threaded end of the conduit for a few minutes. A warmed collar was then quickly screwed home.

In December 1905 a switching station with twelve of these bushings with porcelain collars was installed near Ogden, Utah,

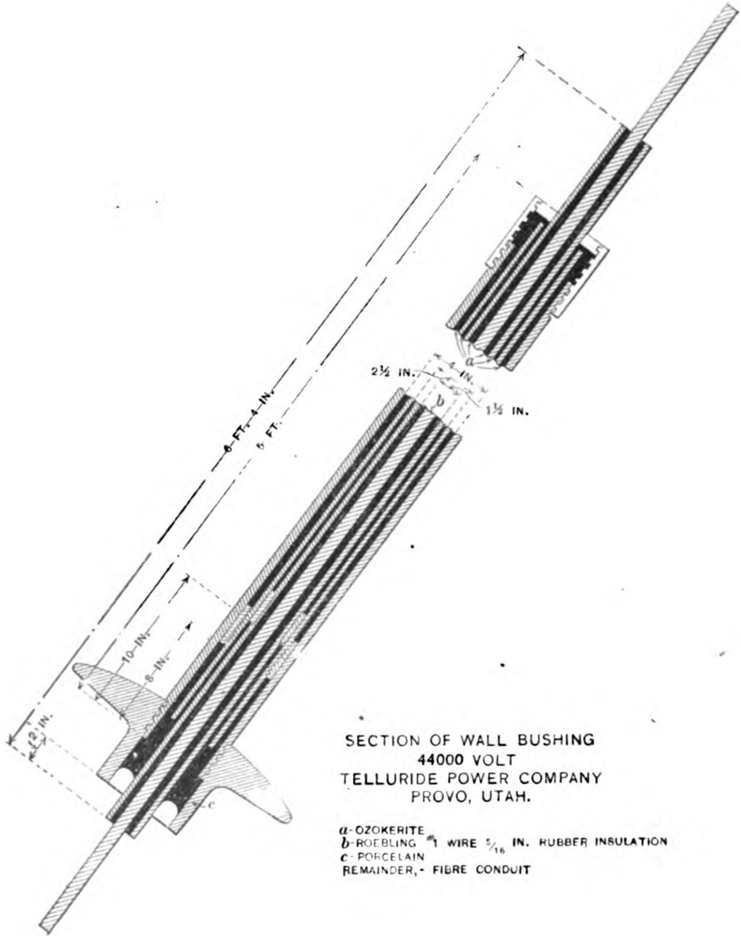

Fig. 6.

the building in this case furnishing protection by a projecting roof. Thus far this arrangement has proved satisfactory.

Tests at the laboratories with the bushings equipped with the porcelain collars showed the weak point between the porcelain collar and the conduit. Dry and wet tests alike broke down along the threaded surface at 97,000 to 104,000 volts. This would indicate that this bushing was likely to give fairly good results even if exposed to the weather, since as far as all line conditions are concerned there would be no danger of breakdown at the normal line pressure or at any voltage that might be caused by switching, since a pair of these bushings would break down at about 200,000 volts. It must be remembered, however, that a lightning storm might easily produce a potential from line to ground that would break down one bushing alone at half this voltage, and this is the condition to be feared. Further tests on this style of bushing show that the whole series of tubes is likely to puncture at about 120,000 to 130,000 volts.

In further pursuing this work for the Telluride Power Company, the writer has endeavored during the past winter to produce a bushing which could be built and installed so as to obtain the following desirable features which are not obtained by other designs:

1. To design a bushing one end of which might be directly exposed to the weather, thus doing away with the necessity of a hood protection which is not only expensive but has been itself the occasion for disaster in the case of severe wind storms which have in several instances torn away the hoods, together with the lines, and parts of all of the buildings.

2. To design a bushing that might be adapted to the roofs of buildings so that lines could be kept sufficiently far from the ground with less height of walls and consequently less expense in building small sub-stations, etc.

3. To design a bushing of such insulating strength that even a building of the cheapest sheet-iron construction could be used for a sub-station in an outlaying district, without danger from breakdown by puncture.

4. To design a bushing which would cost far less in both material and labor than the forms previously used.

To accomplish the first object it was thought advisable to get some reliable insulator which might be so combined with the fibre conduit that the exposed surface insulation of the conduit would not be relied upon at all. To do this it was thought that if an ordinary high-tension insulator having sufficient insulating surface to make it adaptable to an iron pin could be cemented to the conduit this part of the problem could be solved.

Further, the Telluride Power Company secured some refined ozokerite which showed remarkable insulating properties. This material as received was a black wax melting at 150° cent., and although it can be readily broken with a sharp blow when cold, it remains quite tough and slightly pliable when subjected to a steady strain even at 0° cent. An electrical test of this material was prepared by moulding plates about $\frac{1}{2}$ in. thick into each side of which, before cooling, circular lead punchings were pressed with a pair of calipers until the distance between the lead discs was $\frac{3}{15}$ of an inch. The discs were then used as terminals, and the voltage required to puncture was from 120,000 to 130,000 volts.

In looking over the different insulators on hand, a dozen multipiece insulators were found which had been tested by the writer in 1903. These insulators were found to form a good combination for uniting with the fibre conduit. See Figs. 7 and 8. It was decided to use a base and one intermediate petticoat piece of this insulator as shown in Fig. 7, depending upon the ozokerite filling to seal the connection between the conduit and the glass. It was found that much greater mechanical strength, that is, better adherence between the glass and ozokerite was obtained by painting the inside of the insulator with a solution of ozokerite dissolved in gasoline, before pouring the hot ozokerite upon the glass.

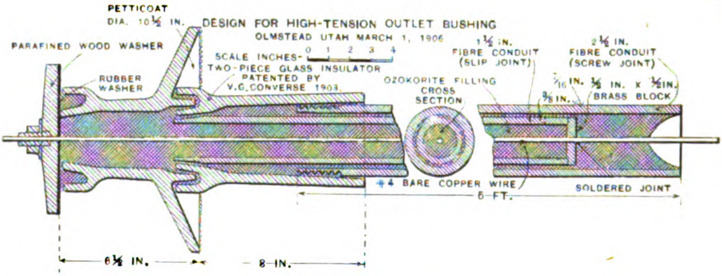

FIG. 7.

In the above arrangment the adaption of the bushing to a roof outlet is easily accomplished by using a pair of wood clamps to hold the bushing directly upon the ridge of the building. The opening between the clamps and around the bushing could be filled with ozokerite wax and the clamp blocks then bedded in a mortar of plaster of paris mixed with plastering hair, and then bolted to the roof.

To improve the insulating qualities so as to make the bushing secure from puncture when placed through a sheet-iron roof, ozokerite was again considered on account of the insulating properties before noted.

On filling all previous bushings it was noticed that the ozokerite seemed to boil and froth considerably when poured into the conduit. Numerous tests were made of the puncturing voltages on bushings filled in the simplest manner. From these tests it was found that actual air-holes were left in the ozokerite, and the puncturing resistance was seldom increased by so filling. This led to an effort to fill the conduit so as to insure a solid mass of ozokerite, anticipating that if this could be accomplished the puncturing resistance would be increased many times.

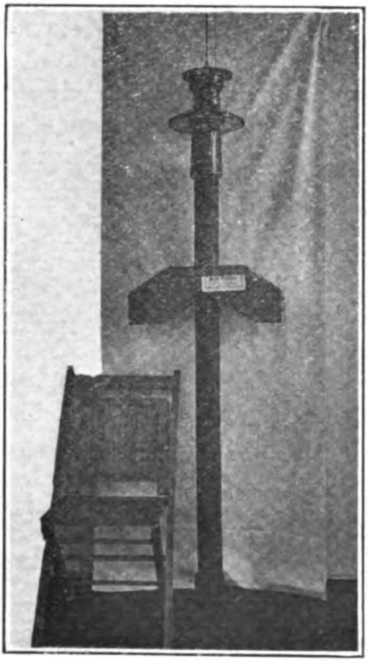

FIG. 8.

In the attempts to insure this homogenous condition of the ozokerite the following experiments were tried: pouring at different temperatures; kiln-drying the conduit; rinsing out the conduit with hot ozokerite before filling; pouring and stirring, and lining the interior of the conduit with heavy brown draughting paper. The latter was finally found to give success after rinsing out with hot ozokerite, or rather filling and then emptying and refilling after heat had driven all froth off the material that had been used in rinsing. The pouring was finally done very slowly, only a foot or so at a time with half-hour intervals, owing to the extreme contraction of the ozokerite in cooling. This procedure kept the top part always hot so that it could sink down as it cooled from the bottom. Several pieces of ½-in. conduit were thus built up with a wire through the center, and the voltage applied to cause puncture reached 140,000 volts and over, while the conduit alone punctured at 49,000 to 57,000 volts.

It should be stated that much labor was thrown away by a burnt lot of ozokerite which was finally discovered by attempting to chew samples both of the material used and of fresh wax. The burnt material would crumble in the mouth and could not be formed into a gum, while the fresh wax would form a tough gum.

With the experience gained from these tests, and the objects before mentioned in view, a complete bushing was now built up according to the following:

SPECIFICATIONS FOR CONSTRUCTING AND INSTALLING 44,000-VOLT OUTLET BUSHINGS.

Constructing. Take a petticoat piece and one base of an insulator, as shown in Fig. 7, clean them carefully and paint the interior surfaces with a solution of ozokerite wax dissolved in gasoline. Place both pieces upon a radiator, or make some similar condition where the glass may be warmed up slowly, finally attaining a temperature of from 150 to 200° fahr.

Prepare a piece of 1½ in. conduit, 5 ft. long, by rolling a piece of heavy brown draughting paper 7 in. wide by 5 ft. long upon a round stick or piece of pipe and insert the paper into the conduit; then let the paper spring out and withdraw the form. Heat some of the ozokerite until thoroughly fluid and free from froth and fill the conduit. A wooden plug held by a thumbtack is sufficient to close one end while filling. When full, empty the conduit (saving the ozokerite for final filling) and place it into a form to hold it straight. A straight piece of plank with a few cleats and screws will serve for this purpose.

The wire should be of bare copper of the size desired, with a ½ in. threaded brass sleeve 1½ in. long soldered 6 in. from one end. Pass the wire through the prepared conduit. A wood block 2 in. in diameter, 1 in. thick with a hole in the center should then be slipped over the free end of the wire, and a brass wire connector should be clamped or soldered back of the block so that it will pull the block against the conduit, when the threaded sleeve is 6 in. beyond the other end of the conduit.

With the conduit in the form and ozokerite in good fluid state and free from froth, begin pouring, the conduit being inclined about 60° with the horizontal. First fill the first 2 ft. and then fill a foot at a time at intervals of about one half hour. Longer intervals should be used in hot weather. Keep the wire tight; heat will loosen it.

When filled and cold, wrap the conduit with wire (or tin foil) using wires about 1 in. apart to within about 14 in. of either end. With the wrapping as one terminal of the testing transformer, and the central wire as the other terminal, raise the voltage slowly up to 120,000 volts.

If the test is without puncture, remove the form and slip the base of the warm insulator over one end—the end may have to be shaved down slightly to make it enter the insulator with a good fit. Slip a piece of 2½ in. conduit over the other end to within a few inches of the glass. Then fill the base of the glass with ozokerite (not too hot) and slip the 2½ in. piece of conduit into the hot wax as far as possible: it should enter an inch beyond the threads at least. After a few moments for cooling, stand the bushing upon the lower end and put on and fill the petticoat insulator piece, lifting it quickly before the ozokerite cools just sufficient to let the ozokerite run into the joint between the two glass pieces. In filling the glasses, care should be taken not to have the ozokerite extremely hot but in a thoroughly fluid condition. The pouring should be done continuously but slowly.

When the material in the insulator has cooled, turn the bushing upside down and fill between the 2½ in. and the 1½ in. conduit pieces with ozokerite. When this has cooled, test for puncture again, wrapping the whole bushing from the glass to within 14 in. of the lower end with a wire for one transformer terminal and the central wire of. the bushing for the other terminal. Bring the voltage up slowly to 120,000 volts as before.

If the test does not puncture it shows that the filling of ozokerite has been successful and the bushing will probably require something over 170,000 volts puncture; since the 2½ in. conduit alone has an insulation resistance of about 50,000 volts. If the inner tube has received a blow or mechanical injury when cold and before being supported mechanically by the 2½ in. outer tube, the two will break down at about 80,000 volts.

After this test, the cap and gasket may be put on top of the insulator and securely fastened by using a ½ in. nut and cut washer.

A pair of clamps should now be made of two 4 in. by 8 in. timbers each about 20 in. long, and bolted to the bushing 1 ft. below the glass insulator. Clamps should be sawed to fit the pitch of the roof to that when fastened to the bushing the slot between the clamps may be filled with ozokerite so as to make them water tight. Several coats of good paint should be applied to the clamps to prevent weather-checking. Four ½-in. carriage bolts with nuts and washers long enough to reach through the ends of the clamps and the roof should be supplied with the bushing.

Installing. Each bushing is designed to go directly through the ridge-pole of the building. The sleeve on the lower end of the bushing may be removed and a hole cut through the ridge just large enough to allow the bushing to pass freely through. The bushing should then be set in place and the holes marked for the roof bolts. The bushing is then lifted up and these holes drilled, after which a bed is made of plaster of paris mixed with hair; the bushing, is then lowered, and the clamp blocks bolted to the roof. .

The bushings should be spaced at least 3½ ft. on centers; preferably 4 ft., and like distances should be left between the bushing and the gable-end of the building.

When the bushing is in place the 2½ in. coupling at the lower end should be screwed back and plugged full of plaster of paris, the purpose being to keep the ozokerite from oozing out.

The bushings are not designed to withstand any appreciable mechanical strain, hence it would be preferable to set a pole on either side of the building to carry the main line over the building, thence dropping short taps to the bushings; or set a " dead end " pole very close to the buildings so that the span of the bushing may be very short and the wires slack. Ground each bushing with a No. 4 bare wire, about three turns both just above the clamp-blocks and just beneath the roof.

According to the above specifications, one bushing was first built and installed through a sheet-iron roof of the transformer house, and 96,000 to 100,000 volts applied between the ground wrapping and the bushing terminal for about three days during which several severe wet snow storms occurred. A special test made during this storm is shown in Fig. 9.

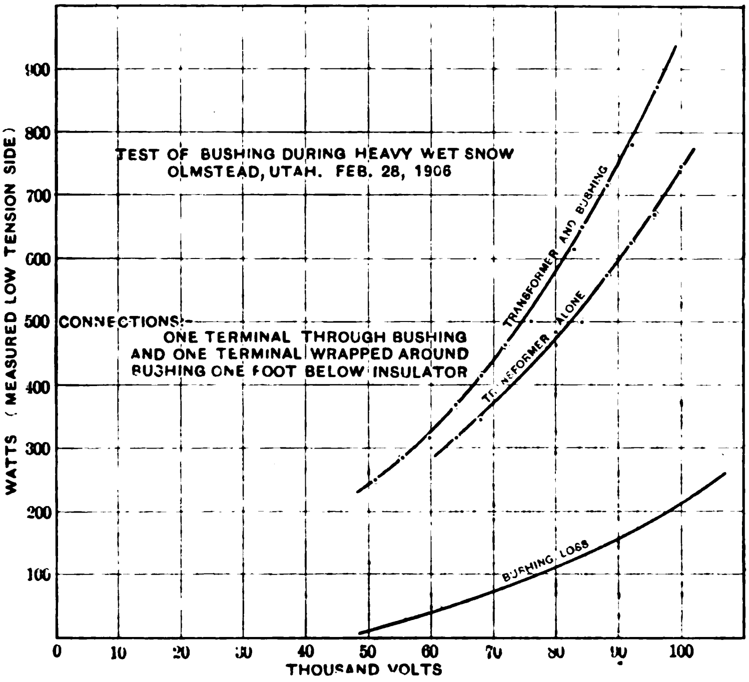

FIG. 9.

After this a voltage of 83,000 was applied to the bushing for over three weeks, with recording instruments on the low-tension side of the transformer recording watts and volts. Although a number of storms, wind and snow, more or less severe, occurred during this time, no appreciable change could be noted on the wattmeter which was sensitive to a difference of about 30 watts.

Shortly after the test of the first bushing, four more were built; three for a small sub-station on the Telluride Power Company's system, and one to complete the pair of bushings for outlets of the 150,000-volt testing transformer house at Olmsted. The cost of building these bushings is given below:

Cost of Material Used For Three Outlet Bushings.

3 pieces of 2½ in. fibre conduit 5 ft. at 9 cents............	$1.35
3 " " 1½ " " " " " " 5 "	0.60
3 " " No. 4 copper wire, each 7 ft. long, 3 lb. at 26c...	0.78
3 insulators consisting of one middle piece and base (estimated)..............................at 27c.	0.81
Three 2½-in. fibre conduit couplings threaded 15 cents...	0.45
20 lb. of ozokerite at 7 cents.........................	1.40
1 box tape..	0.29
18-½ in. by 9 in. carriage bolts..........................	0.65
6 in. ½-in. brass rod, ½ lb...............................	0.15
1 lb. ⅛ in. rainbow packing, at 66 cents.................	1.32
36 sq. ft. common lumber..................................	0.83
25 lb. plaster paris......................................	0.16
5 lb. plastering hair, at 2 cents........................	0.10
Labor, one man 3 days (estimated)........................	9.00
	$17.89

A true comparison is hard to obtain in regard to the cost of the various styles of outlets that have been mentioned. It is probably a safe estimate to say that in the case of bushings requiring hoods, the hoods alone cost from $12 to $30 per bushing. The bushing at Olmsted station cost $25 each to build, and the cost of hooding per bushing was about $30. The porcelain collared bushings have cost $18 to build, and the hooding may be estimated at $12 each. With the bushing designed and built under the above specifications, it will be seen from the itemized bill that the cost per bushing is about $6.00 while the cost of installation and hooding is practically zero.

All laboratory testsindicate that the electrical properties of the new bushing are far superior to those of other designs. The only questions that may arise are in regard to the durability in service, when the ozokerite is subjected to such temperature and mechanical strains as cannot be avoided.

A paper presented at a meeting of the Baltimore Branch of the American Institute of Electrical Engineers, January 11, 1907, in the Physical Laboratory of the Johns Hopkins University.

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(*Subject to final revision for the Transactions.*)

UNDERGROUND TRANSMISSION AND DISTRIBUTION OF ELECTRICAL ENERGY.

BY CHARLES E. PHELPS.

The faults in underground cables naturally classify themselves as follows:

1. Defects in the cable itself.
2. Injury received during installation.
3. Faulty workmanship.
4. Mechanical injury.
5. Electrolytic action.
6. Certain external injuries, the cause of which may not be conclusively established.

And to these six may be added the injuries which occur to cables not strictly underground, but which are above the surface of the ground on poles, etc., making connection with aerial conductors. This latter is uniformly the result of imperfect covering protection, or results from contact with the cable sheath of aerial wires; they can hardly be classed with the faults of underground cables.

Referring to the other six classes of faults, the first three; viz.

1. Defects in the cable itself,
2. Injury received during installation,
3. Faulty workmanship,

should be sufficiently provided against in the contract for the cable and in the character of conduit construction, that they may be developed on the breakdown test which is invariably applied to a completed cable before putting it into continuous service. This test usually requires that at least double the ordinary working voltage shall be applied to the insulation of the cable; that is, between conductors and ground, for various periods of time depending upon the judgment of the purchaser and acquiescence of the contractor. The test should never be pushed to a point where the insulation is liable to be pin-holed by the strain of the test voltage, and experience has generally pointed to the continuance of the test voltage for from one to two minutes' duration, instead of thirty or more minutes which have often been specified. Under this test the defect should be developed and the obligation should, by contract, be imposed upon the contractor to make it good. If it should have been caused by any defect in the conduit construction the cable contractor would, of course, be blameless. The other faults:

4. Mechanical injury,
5. Electrolytic action,
6. Damage to cable above ground.

All these are of purely external cause.

In order to illustrate this feature more prominently, below is given a tabulated record of cable faults in this city for the seven years ending December 31, 1906, together with the lengths of cable in use in each year. This tabulation includes all classes of cables:

13,000 = volt alternating-current, three-conductor cable.
6600 = " " " " " "
2300 = " " " " " "
1000 = " " " two- " "
500 = " street railway feeders.
250 = " three-wire distribution.
Telephone cables from 5 to 400 pairs,
Telegraph " " 20 to 200 wire,

and various smaller cables used for burglar and fire alarm and other signalling purposes, including the police and fire alarm wires of the city. In fact the table includes injuries to all those classes of wires which are found to be necessary in the activities of any large and growing city. Summarized by classes of faults and by years, the table is as follows:

It should be noted in connection with the table above given that damage under head of gas explosions was not the immediate result of the explosion, but was caused by the falling of debris and burning gas. No cable has been directly injured from any gas explosion under observation. Also, that the damage under " Flood Water—Jones' Falls " was due to the carrying away of cables on temporary suspension under a bridge crossing Jones' Falls, by heavy timbers carried down by flood water.

Class	Nature of Damage	1900	1901	1902	1903	1904	1905	1906	Total
1	Defective cable. .	—	1	—	—	—	2	—	3
2–3	Damage during installation.	—	—	—	3	7	4	10	24
4	Damage by picks, bars, etc.	—	2	6	6	13	27	4	58
4	Flood water, Jones Falls.	—	—	—	1	—	1	—	2
4	Gas explosions. . . .	1	—	—	—	1	—	—	2
4	Rats.	—	—	—	—	—	—	5	5
4	By workmen in manholes.	—	—	—	2	3	4	4	13
5	Electrolytic action	1	—	2	15	5	4	4	31
6	Cables above ground.	—	1	1	—	—	—	—	2
7	Unknown.	—	—	—	—	—	7	1	8
	Totals.	2	4	9	27	29	49	28	148
Feet of cable in operation at end of each year.		106.779	236,266	470,154	708,152	853.948	1,246,443	1,535,294	
Fault per 1000 ft. of cable.		0.018	0.017	0.019	0.038	0.034	0.039	0.018	

Summary of Cable Faults

Class	Nature	Number of faults	Per cent. of whole
1.	Defective cable.	3	2
2.	Damaged in installation.	24	16
3.	Mechanical injury.	80	55
4.	Electrolytic action.	31	20
5.	Cables above ground.	2	1.5
6.	Unknown causes.	8	5.5
		148	100

The percentage in importance of each class of fault to the whole number is:

1. Defective cables. . . . . 2 per cent.
2. Damaged in installation. . . . . 16 "
3. Mechanical injury. . . . . 55 "
4. Electrolytic action. . . . . 20 "
5. Cables above ground. . . . . 1.5 "
6. Unknown. . . . . 5.5 "

This is for the whole period of seven years; the record of the year 1906, just past, during which time there were over 1,500,000 ft. of cable in operation, is as follows:

1.	Defective cables	none
2.	Damaged in installation	10
3.	Mechanical injury	13
4.	Electrolytic action	4
5.	Cables above ground	none
6.	Unknown	1

a total of 28 or $\frac{18}{1000}$ per 1000 ft. of cable in operation.

In considering the tabulations of cable faults, these data must be understood to show actual existing and not sporadic conditions; that not only do they cover a considerable period of time but they cover also a time during which progress in this particular branch of the art was undergoing great changes. A part of the time may even be taken as experimental. In addition to this, the data for the years 1904 and 1905, shown in these tables, will suffer in its application to a normal situation by reason of the apparently high percentage of faults developed on account of mechanical injury.

Out of a total of 80 faults by mechanical injury for seven years, exectly one-half, or 40 of them, occurred during the years 1904 and 1905, although in 1906 there were but four, while the amount of cable in use was much greater.

This disproportion is easily explained by pointing out that during 1904 and 1905 all street improvements consequent upon the fire of February 1904 were carried out. Street lines and grades were changed, necessitating a similar change in conduits and of cables within them. A great many men were employed upon all sorts of work and naturally the underground system has to stand its share of damage.

In studying the list of cable faults you will see that, barring the sole element of human frailty, all the faults may be to a large extent anticipated, and in a large measure avoided. By analyzing these failures, you will find some definite reason for each of them to which a remedy can be applied. I do not intend to convey the impression that a cable system can be developed which will never be fault-proof, because the conditions under which it is operated are not those of a parlor game; but one has to deal with men and materials that are by no means perfect.

I can perhaps illustrate the conclusion which I desire to convey to you. Suppose, say 20 important companies on this continent engaged in the same character of electrical business were to keep accurate records of the performance of their underground equipment under actual operation, with clear explanation of the conditions surrounding and the effect of each cable fault; and suppose that all these 20 separate sets of data were available to each one of the companies concerned so that each would have, in addition to its own data, those concerning the cable performance of 19 other companies. Suppose now you had these data in hand, what would be the result? You would eagerly search out those of the companies which showed few faults where you were subjected to many of the same kind, and you would get in touch with them and learn in what particular they had succeeded where you had failed. In the same way you would be called upon to explain your successful methods to certain others who had failed where you had succeeded. This is a process which seems so easy, so simple, and so inexpensive when the great benefits that would accrue are considered, that it seems surprising it is not an almost universal custom. I cannot refrain from backing up this statement by saying that this spirit of coöperation and coördination is one of the important elements which has maintained the preeminence of the Bell Telephone Company in its particular field of operation, judging solely by results from the point of view of an outside but interested observer.

Before closing this paper I ask your consideration to a brief review of this particular subject which may really be termed the crux of the whole situation. Taking the cable faults in the order they appear on the chart, the first three:

1. Defect in cable itself,
2. Damage during installation,
3. Faulty workmanship,

should be covered by the contract for purchase and installation of cable, and they should be "smoked out" by the installation test before described. Owing to the fact that the factory test of cable before shipment is much more severe than the installation test, and that the factory test is made on the cable while submerged in water, it is more than probable that any fault developed in the body of the cable itself will be caused either during shipment or during installation.

It will generally be impossible to determine on light and power cables, which was the real cause, for the effect of the breakdown is to destroy the evidence entirely; the affected part of the cable will vanish to parts unknown.

Faults due to installation are in general due to four causes;

1. Defective conduit structure,
2. Reckless or improper methods of pulling cable into ducts,
3. Rough handling or too sharp bends in manholes,
4. Badly made joints.

I think it sufficient simply to enumerate these causes to indicate the prevention or remedy.

Faulty workmanship may occur either during installation or later, due to additional taps or connections being made to an existing cable. Here the remedy, aside from the employment of only skilled and careful workmen, is to provide a manhole suitable for the conditions under which this work is to be done. There should be plenty of elbow-room, and cleanliness is one of the best friends to the underground cable. Even in a city without sewers, the expense of consistent drainage of manholes by expensive methods is justified.

Mechanical injury may come from without through the agency of the energetic man with the pick who generally never works so hard as when he is hacking away at something he has no business to hack; or it may come by reason of improper use of the manhole by workmen; or from such an unusual source as the despised rat, which has been dignified by what I hope are five obituary notices in our exhibited list, under the year 1906.

I hardly feel able to point out any remedies against this prolific cause of cable trouble that have not already perhaps occurred to you, but there is one which comes from within and which often and unnecessarily results in trouble and is easily avoided. This, as is usually the case with internal cable troubles, concerns the manholes. I have myself recently seen inside the manholes of an important underground system where the cables therein were so run through the manholes that it is impossible for a workman to get to the floor of the holes without using these cables as a step ladder. This was the case, not in a single manhole, but in many of them. Apparently the manholes were built simply because every other underground system had them, and they exhibited utter disregard of their permanent use by the cable equipment for which they were built.

DISCUSSION ON "RECENT INVESTIGATION OF LIGHTNING PROTECTIVE APPARATUS" AT NEW YORK, DECEMBER 28, 1906.

Ralph D. Mershon: There is probably no other natural force amongst those with which modern engineering has to deal of which so little is intimately known as of lightning. In most engineering problems it is possible to control and reproduce at will the conditions actually existing in practice, and thus study the phenomena resulting therefrom; or, if this is not possible, there is a natural repetition of the phenomena of sufficient regularity so that they can be studied and traced back to the elements on which they depend. With lightning this is not so. The conditions existing in practice cannot be controlled, and the elements involved are so enormous, numerous, and variable that it is impossible to reproduce them. The natural repetition of phenomena is at such irregular intervals, and the phenomena, when they do occur, are apparently so erratic, due to the number and variability of the elements on which they depend, that no satisfactory searching study has been made of them.

As a result, we have no intimate knowledge of lightning and the conditions governing it and its effects. Theorizing in regard to it is, in the lack of definite experimental data, of little value. Theory cannot be much more than guessing, and, within certain limits of probability, one guess is just about as good as another. There is about as much use in trying to forecast the weather for a certain day next year as to tell what lightning will do.

In view of the above, I am always more or less sceptical of any theories advanced in regard to lightning or lightning protection; at any rate, unless actual practice has shown that there may be some foundation for the theory. Even though practice should uphold the theory, as it has in a few instances, I should be sceptical, for, as has been the case more than once, the next installation may upset both practice and theory.

We are, I think, at times too much inclined to theorize without a sufficiency of data; to attempt to reason from a few facts pieced out with such fundamental data as we have at hand, instead of first experimentally obtaining at least a fair amount, if not all, the information possible, directly applicable to the subject in hand, and then endeavoring to formulate a theory. The paper under consideration this evening is, it seems to me, somewhat open to criticism in this regard.

By means of the data of Figs. 4 and 5 obtained on one transformer, having a certain internal electrostatic capacity and subjected to a frequency or steepness of wave-front, which may or may not approximate that in the case of lightning, the endeavor is made to specify, within certain limits, the inductance which will form an effective protection. I think that if it were worth while, it could be shown that with other transformers and other frequencies of discharge, the criteria by means of which the writer of the paper has fixed the limits of effective inductance would be very materially modified. In my opinion the author would have done much better to have turned to his Figs. 6 and 7 and said: "Here are curves showing what in practice we can stand in the way of reactance. Guided by them, let us use all the reactance permissible." Even then, I should not be inclined to agree with him as to the advisability of choke-coils. A choke-coil of any considerable size is an awkward and an expensive thing. It is expensive not only in itself, but in the space it takes up, and, besides, it usually adds complication to the station wiring, the high-voltage wiring which it is especially desirable to keep simple.

If we must have choke-coils, let us put them in the same case as the transformers, and so save the complication in station wiring. Better still, let us do away with them altogether, and put such amount of insulation as may be necessary on the end-turns of the transformers, such amount of insulation as will take care of a considerable strain between the end-turns. Then, if we use a low-resistance arrester or its equivalent, we shall, I think, have ample protection.

As between a high inductance choke-coil in connection with a high-resistance arrester, and no choke-coil in connection with a low-resistance arrester, I much prefer the latter. And it is possible to have the low-resistance arrester equipment, as I will show later on, even though the electrolytic arrester described by the author should not prove to be all that it promises, but which I hope it will realize.

I have known of many cases where choke-coils of considerable reactance in connection with arresters of considerable resistance have failed to protect under severe conditions, but I have never known a case where very low-resistance arresters or fused arrester-gaps have failed to protect. I have known of a number of cases where apparatus has been damaged not only in spite of the choke-coils installed with it, but apparently because of them, due to disturbances on the circuit other than lightning, and a piling up of potential of the transformer terminals,probably because the choke-coil kept the transformer from freely ridding itself of a charge set free in its windings. Such happenings as this would seem to indicate that if a choke-coil were used, an arrester should be installed on each side of it.

Transformers will undoubtedly be more expensive with heavily insulated end-turns, but I think that in most cases the extra expense will be little, if any, greater than that of the separate choke-coils and the space they take up. This will certainly be the case for such extra insulation as will be necessary with a low-resistance arrester. The demand for a number of voltage taps need not interfere with the end-turn insulation, if the desired variation in the length of the transformer winding be obtained at the middle of the winding; that is, at the junction of the two halves of the winding instead of at the ends. Multiple series connections of high-voltage windings ought not to be often required, and I believe that as time goes on they will be required less and less; but even where they are required, I believe that the same heavily insulated end-coils might be used as end-coils for both series and multiple connection, and meet most of the requirements in practice.

I am inclined to doubt the correctness of the opinion of the author seems to hold relatively to the resistance of lightning-arresters. I have reason to believe that under some conditions even a high-resistance arrester will be of benefit; and I do not think the author himself is prepared to state that the high-resistance arresters now installed afford no measure of protection. I do, however, agree that a low-resistance arrester is desirable at all times, and absolutely necessary for proper protection under some conditions.

It is possible to have a system of lightning protection which will automatically adjust the resistance of the path to ground to that value necessary to take care of the discharge. Suppose we assume that the magical 400 ohms worked out by the author is the resistance which must not be exceeded under extreme conditions. Suppose that with a given voltage and generating capacity, a horn, or other suitable arrester, will operate satisfactorily, if it has, say, 2000 ohms in series with it. Suppose we have five such arresters connected to each line wire, each arrester having 2000 ohms in series with it. Set one of the arresters on each wire for low-striking electromotive force; another arrester on each wire for a higher striking electromotive force; another for a higher, and so on to the fifth arrester, set for the highest striking electromotive force which the apparatus to be protected can, for a short period of time, safely withstand. Now suppose there is a rise of voltage on the line under such conditions that one 2000-ohm path to earth will properly discharge it. The lowest gap will flash over and discharge take place through the 2000 ohms in series with it, this discharge keeping the electromotive force of the disturbance down below that necessary to strike across the next higher gap. If a disturbance occurs requiring a 1000-ohm path, the lowest gap will strike, also the next lowest, giving two 2000-ohm paths in multiple for the discharge. Similarly, with other disturbances more severe, more and more of the gaps will flash over until, in the extreme case, all five gaps will be active and the resistance of the combined path to earth will be 400 ohms—that specified by the author. If desirable, there might be one or more gaps having fuses in series with them, so that when they acted the discharge would have a path to earth of practically zero resistance.

The above scheme of lightning protection might be carried out to any extent, and any desired number of gaps be used, the result being that under any given condition the path to earth would have a resistance as low as necessary to take care of the disturbance upon the line and that the disturbance to the transmission system, due to the dynamic current which would follow the lightning discharge, would be proportionate to the necessities of the case. In an extreme case the disturbance to the system due to the dynamic current over all the gaps might be such as to cause a shutdown, but the apparatus would be protected. A shutdown without any damage to the apparatus is preferable to a shutdown resulting in apparatus which has to be patched up; fortunately, such extreme disturbances are rare.

Such a system of protection as that described would apply not only to disturbances requiring a path to earth, but also to discharges passing from a conductor to conductor. It is to be noted that in such a system the operation of successive gaps not only reduces the resistance, but also the inductance of the path.

I have for some time past made use of the scheme of lightning protection outlined above, except that only three sets of gaps are used on each line wire, and the highest gap has a fuse in series with it. My experience so far, extending over one lightning season, has been very satisfactory. A previous experience, extending over several seasons and with a system of protection similar to, but much less elaborate than, that with the three gaps just described, was also satisfactory. I have come to believe that such a system is about as near to being an absolute protection for station apparatus as could be expected. This assumes, however, that the apparatus has that margin in insulation strength which good apparatus should have, enabling it for a short period of time to withstand considerably more than its normal voltage.

The electrolytic arrester described by the author is a very interesting and promising piece of apparatus. I have seen it in experimental operation, and, so far as experiments go, it seems as if it might be effective. It remains, however, to be seen how it will behave in practice; what difficulties may arise due to the evaporation or freezing of the electrolyte, or to the sudden formation of vapor, in the case of a lightning discharge of extreme severity. Any or all of these troubles may be met with, but no doubt they can be overcome, the latter possibly by using a number of these arresters in multiple, either in series with gaps of the same size or set for different striking electromotive forces. It looks as if we may at last have the ideal lightning-arrester and I sincerely hope that this is the case.

In my opinion a very desirable requirement of a lightning-arrester is that it should be capable of being installed outdoors. I believe that as time goes on more and more high-voltage apparatus will be installed outdoors, instead of in a building. I think the time will come when not only lightning-arresters, but bus-bars, transformers, and even automatic circuit-breakers, where such are used, will regularly be installed outdoors. It seems rather illogical, and, from some standpoints, almost ridiculous, to instal high-tension bus-bars in a building with barriers and all sorts of other complications, when the lines led off the bus-bars go immediately out of doors, unprotected, and often installed upon very questionable line structures.

I understood Mr. Jackson to say that in obtaining Fig. 4, the middle point of the transformer was grounded, so that the discharge went through half of the transformer winding only. I would like to ask if he took any observations similar to those of Fig. 4 on the other half of the transformer winding? It would be interesting to know what voltages could be obtained on the other half of the winding? It would have considerable bearing on his statement indicating that the iron renders ineffective the space occupied by it, so far as the inductance of the coil is concerned.

Chas. P. Steinmetz: This paper deals again with those four elements which. since the earliest days of electrical engineering have constituted the parts of lightning protective apparatus; namely, the resistance, the inductance, the spark-gap, and the circuit-opening devices.

In regard to the reactance or choke-coil, I also fully believe in the effectiveness of the reactive-coil. It is obvious that the reactive-coil cannot be considered as a protection against all of the manifold manifestations of atmospheric electricity or internal surges; anybody can see that against a slow accumulation of electrostatic charge on the system by induction from the clouds, etc., whereby the total system rises as a whole in potential above ground, a reactive-coil cannot protect; also, it cannot protect appreciably against a very low-frequency surge where the oscillation is of enormous magnitude and of a frequency not much above the normal line frequency. Then any amount of reactance which it is permissible to put in circuit, will not offer a sufficient protection. Hence, the reactive-coil is not a universal protective. However, it can be shown experimentally that at least against high-frequency oscillations, against travelling waves of steep wave-front, the reactive-coil offers a very marked and satisfactory protection.

I cannot agree, however, with the paper regarding the numerical values of the minimum effective reactance. I believe the numerical values given are not correct general conclusions, but merely incidental to the particular conditions of the experiment from which they were derived. The spark-gap was connected across the 200 end-turns of the transformer, and it was found that the electrostatic stress across these 200 turns of the transformer, without reactive-coil, or with very small reactive-coil, had an equivalent spark-gap of one inch; that is, about 20,000 volts. The spark-gap was reduced to one-half by an inductance of about 7 millihenrys. If the writer of the paper had connected the spark-gap, not across 200, but across 20 end-turns only, he would have obtained a curve similar to that given in Fig. 5, but with an entirely different set of abscissas, and would have found as minimum effective inductance sufficient to reduce the spark-gap to one half, about one-tenth of the value given in the paper. If he had connected the spark-gap across the two end-turns, probably the minimum effective reactance would not have been 7 millihenrys, but something like 0.07, or about one hundredth part of the value recommended, so that the effective reactance depends on the number of turns across which the electrostatic stress is observed. The error made by the writer is one of those into which I believe all of us who have done experimental investigating and drawn conclusions from it have fallen at one time or another; that is, to draw general conclusions, especially regarding the magnitude of a phenomenon, and then afterward find that these conclusions are not general, but special results of the particular conditions under which we experimented.

Let us see what happens if a voltage is suddenly impressed upon a transformer, as here the voltage of the Leyden jar or the condenser, of about 50,000 volts, or by an atmospheric oscillation or travelling wave, etc., or the line voltage when connecting a transformer into the circuit. Before closing the circuit the transformer windings are at zero potential; in the moment of closing the circuit 25,000 volts are put on one terminal; that is, on the beginning of the end-turn, but the ends of this turn and the second turn are still at zero potential; and so at this instant the full potential of 25,000 volts exists across a single end-turn. An instant—a fifty-millionth of a second or so later—the current has passed along the first end-turn, and voltage exists at the beginning of the second turn, while the third turn is still at zero potential. In this instant the full potential of 25,000 volts is across two end-turns; that is, each gets about half of the voltage. Again, in another fifty-millionth of a second, the potential distributes across three turns, then across four turns, five turns, etc. You see the maximum potential difference which can exist without any reactive-coil across the first turn is the full voltage of 25,000 volts. The maximum potential difference across the second turn is half, half being across one turn and half across the other; across the tenth turn it is one-tenth, and across the 200th turn it is $\frac{1}{200}$ of the full voltage.

Suppose we take out the first nine turns and put them outside the transformer as a reactive-coil. The first transformer turn, then, is what was before the tenth turn; and at the same discharge, the same impressed voltage, the maximum potential at the first transformer turn is the maximum potential which was formerly got at the tenth turn; that is, it is one-tenth of the impressed voltage. That is, by putting nine transformer turns outside of the transformer and in series therewith, as a reactive-coil equal to only nine transformer turns, very much less than the minimum referred to by the speaker, the maximum electrostatic stress which can exist anywhere in the transformer is reduced to one-tenth of the previous value. But the maximum electrostatic stress across the 200th turn is reduced only from $\frac{1}{200}$ down to

$\frac{1}{209}$ of the full voltage, because it is now the 209th turn, and the sum of all the electrostatic stresses across the first 200 turns is not appreciably reduced at all. Hence if we use a reactive-coil equivalent to nine transformer turns, and measure the electrostatic stress across the first 200 turns, we find no appreciable effect, while actually we have reduced the maximum electrostatic stress on the most exposed part of the winding, the first transformer turn, to one-tenth of the previous value; that is, we have secured a very high protection.

After all, if a transformer breaks down internally by a sudden discharge, it is not the 200th turn which breaks down, or the 100th turn; it is one of the very first turns, where the electrostatic stress is the maximum, and where, therefore, there is a maximum potential difference many times greater than given by the data in the paper, which data give, not the maximum stress anywhere in the transformer, but the value integrated over a very large part of the transformer; that is, an average which bears no direct relation to the maximum, against which we have to guard.

I do not need to go into this matter further because this phenomenon of distribution of potential in the transformer windings at a sudden application of voltage has been very fully discussed, in the classical paper read before the American Institute of Electrical Engineers four years ago by Mr. Percy H. Thomas.* There this phenomenon is very fully explained.

I think it fortunate that such high reactance is not necessary, but that a very great reduction of the maximum electrostatic stress results from very moderate reactance; that is, by a reactive-coil which does not occupy as much space as the whole transformer. Obviously, the more reactance is put in the circuit, the more the stress on the transformer is reduced, but very soon it becomes a question whether it is more economical to build a larger reactive-coil, or to increase the insulation of the transformer end-turns. To insulate between the end-turns against full voltage is difficult, and an additional reactance is therefore desirable; but as we have seen, a reactive-coil of very few turns only already reduces the maximum stress at the end-turns to a very few per cent. of the maximum possible stress, and so to a value against which sufficient insulation of the end-turns can easily be provided for without appreciable increase of size and cost of the transformer. A moderate size reactive coil and additional insulation of the transformer end-turns is preferable, because it does not make it necessary to have such a very large reactance, which spoils the regulation of the system by two per cent. or becomes impracticable altogether on a large-current low-voltage system.

This feature is also important in considering the question whether the reactive-coil is a reactive-coil at all. It might also be stated as a conundrum for high-frequency phenomena:

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* TRANSACTIONS of A.I.E.E., 1902, Vol XIX, p 213.

when is a reactive-coil not a reactive-coil? In speaking of reactive-coils as guarding against high-frequency oscillations, we always assume that such a coil contains inductance and a very small resistance; but we usually forget that it also contains distributed capacity, that there is a capacity from turn to turn which may be relatively small where circular conductors are used. There is, too, a considerable distance between turns; this

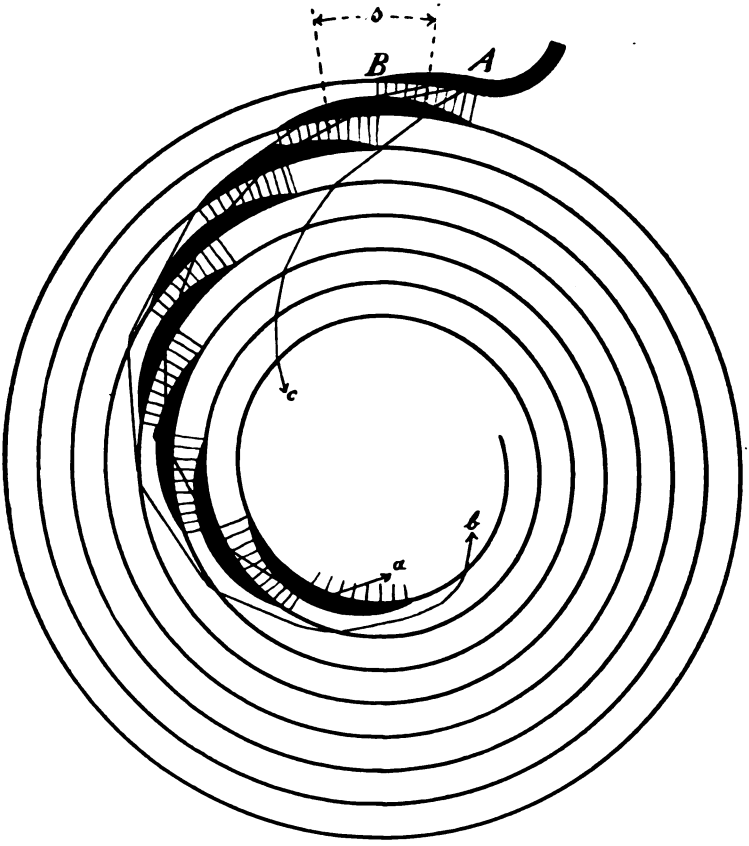

FIG. 1.

becomes very much larger where flat conductors wound in a flat coil are used, very much larger where we submerge the reactive-coil in oil, due to the higher specific inductive capacity of the oil, the specific capacity of the oil being two or more times that of air, and due to the shorter distance between the turns, permitted by the higher disruptive strength of the oil. At such very high frequencies as are produced by spitting from the line, by brush and spark discharges, by an arcing ground on one side of an isolated three-phase system, and many other such phenomena, the electrostatic capacity of the reactive-coil begins to be appreciable.

What happens I can sketch only roughly. Let the reactive-coil be shown diagrammatically in Fig. 1, as a spiral, with the turns inside of each other. If a discharge enters at the lead A, if the frequency is high enough the current does not go around the complete spiral, but the current passes from one conductor to the next conductor through the capacity between the turns as a condenser. The current, starting at full value at A, gradually tapers down in the first turn, to nothing at B, within a limited distance; in the second spiral, the current is zero at A and gradually rises to a maximum at B. In the same way the current passes from the second to the third turn, etc. The current thus transfers across from turn to turn by the electrostatic capacity between the turns, gradually rising in each turn, by transfer from the preceding turn, and fading out again by transfer to the next turn. Thus the current flows a short distance only in each turn, but does not go around if the frequency is high enough.

Assume that:

L = inductance per unit length of conductor,

C = capacity per unit length of conductor,

N = frequency of the oscillating current, or frequency representing the steepness of the travelling wave.

s = length from condenser center to condenser center, then

$C\,s$ = capacity of each of these condensers formed by successive turns.

$L\,s$ = inductance of the short path of the current from condenser-center to condenser-center.

The current has an infinite number of paths, a, b, c, etc.

There is one path, on which the capacity reactance: $k = \frac{1}{4NCs}$ equals the inductive reactance: $x = 4NLs$ and the total impedance thus is a minimum, equal only to the ohmic resistance; that is, this path is non-inductive, and the current flows across the reactive-coil on this path.

In this case:

$$k = x$$

it follows:

$$s = \frac{1}{4N\sqrt{LC}}$$

or:

$$N = \frac{1}{4s\sqrt{LC}}$$

That is, if:

L is the inductance, C the capacity per unit length of the conductor, if the frequency of discharge is high enough, the current does not follow the turns of the reactive-coil, but passes in a spiral, non-inductive path across the coil, and the reactive-coil is not a reactive-coil. The frequency where *s* equals the length of one turn, gives the limiting frequency at which this phenomenon is completed, at which the last inductance has disappeared. This limiting frequency is very high, somewhere in the range between 10,000,000 and 100,000,000 cycles, but it is a frequency which does occur in discharges from a line, not a discharge which comes from a long distance, but a frequency which occurs where a steep wave approaches a station, and then meeting any obstruction spits over to other conductors near by, or into space. This phenomenon has to be considered when dealing with reactive-coils at very high frequency, and may be one of the causes why reactive-coils occasionally do not protect, but let extremely high frequency pass, just as well as low frequency, and act only in the case of intermediate frequencies.

The phenomena resulting from distributed capacity in the reactive-coil at extremely high frequency are obviously more complex than those illustrated above. For instance, during the decrease of current by transfer to the next turn, across the intervening capacity, a transfer back to the preceding turn takes place also, and so a second parallel path of current, of lesser intensity, appears ahead of the main path *a*, as shown by *b* in Fig. 2, a third path at *b'*, etc., and in similar manner, back of the main path, secondary paths *c*, *c'*, *c''* etc., appear. These secondary paths, overlapping at the opposite side of the coil, result in various interference phenomena. Thus if all the turns of the coil are of the same effective length, at those frequencies at which the length of turn is a multiple of *s*, resonance effects intensify these standing waves; while at an intermediate frequency the standing waves passing around the coil in opposite direction, meet in opposition and thus neutralize. Again, with a coil in which the diameter of the turns tapers, resonance appears in some, opposition in other turns, and radially distributed nodes appear at all frequencies, shifting with a change of frequency

Coming to the next element of the lightning-arrester, the series resistance, I fully agree with the sentiment—which can be read between the lines of the paper—that the best series resistance is the one of lowest value, and the lowest value is zero. There are, however, two points of view; one point is that of the designer of the lightning-arrester, and the other that of the operator of the transmission system. For the protection and safety of the lightning-arrester, the higher the series resistance the better; and it is extremely difficult to produce a lightning-arrester without series resistance, which is really safe against self-destruction. But from the point of view of effective protection of the system, any series resistance is objectionable. Here also the writer of the paper has calculated numerical value for one particular condition, and concluded therefrom that 400 ohms series resistance is permissible. This conclusion is justified only for the particular condition where an electrostatic charge of 100,000 volts appears somewhere on the line and approaches the station along the line. There may be other disturbances in which this series resistance is not permissible. It may happen that in a station a short circuit takes place, and instantly ruptures. For instance, by some overload the circuit opens, but the switches fail, as should not happen, but still occasionally happens; that is, the switches burn up by a flaring arc and the short-circuiting arc ruptures itself spontaneously, explosively, as such arcs occasionally do at the maximum of the current wave. That means a rupture of the short-circuit current. That current cannot instantly cease in the system, but continues to flow, and not having a path merely backs up as voltage. It is obvious that in any large system the voltage produced by the instantaneous rupture of the maximum short-current circuit cannot be appreciably relieved by the discharge over a 400 ohms resis-

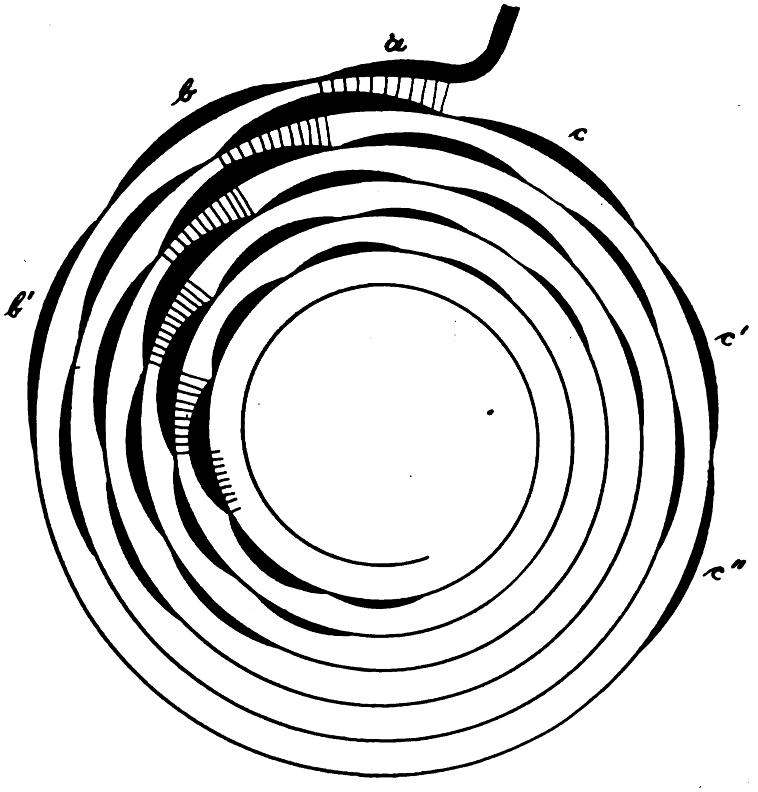

Fig. 2.

tance. A circuit with 400 ohms resistance will not reduce the destruction to any appreciable extent. For instance, at the Milwaukee convention last May, Mr. Osgood of the New Milford Power Company reported on the low-frequency surge in his system produced by some person who threw an umbrella handle into the transmission line at 33,000 volts. Or in cases like that of a metropolitan system, where a short-circuit oscillation or surge occurred with a current sufficiently large to bend heavy copper bars, and at a voltage jumping across seven inches of air. No protective device with 400 ohms series resistance would have any appreciable effect in relieving such a surge. In the case of 400 ohms series resistance, or any series resistance, there always comes a point where the magnitude of the surge is such that the series resistance becomes fatal.

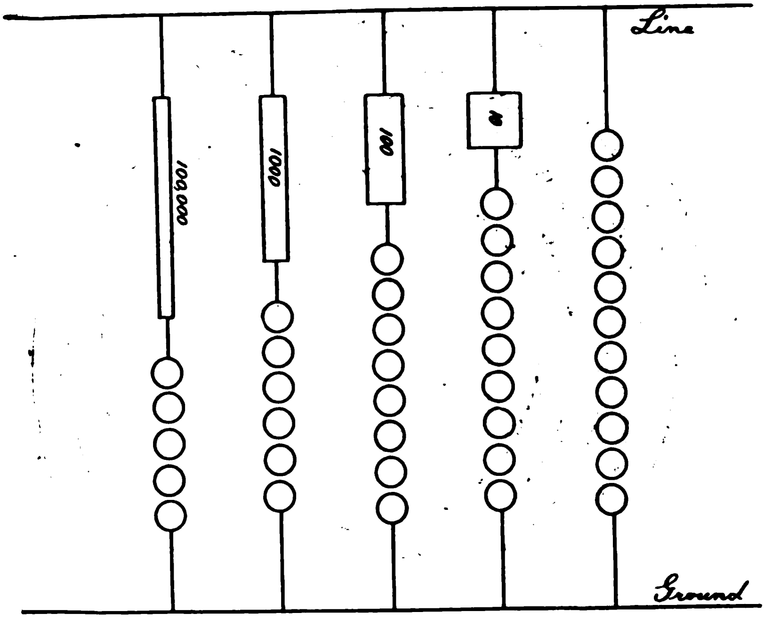

Fig. 3.

In regard to the electrolytic arrester, I may say that it is a very interesting apparatus. I know that Professor Creighton has been working on this type of lightning-arrester for several years, and I believe some such arresters have been out in commercial service on high-potential lines for a year or two. I expect we shall hear something of the performance of these arresters either to-night, or at the meeting of the Institute for which Professor Creighton promises a paper.

In regard to Mr. Mershon's proposition, I approve of his type of lightning-arrester, a number of spark-gaps set for different voltages, with different series resistance, a low-voltage spark gap with a very high resistance, and then a little higher voltage spark-gap with somewhat lower resistance, etc., so giving the current the choice either to jump only the last spark-gap with high resistance limit, or the next one with lower resistance, or the next, etc. We know that a number of small gaps in series are more effective than one large gap in opening the circuit, so that several gaps in series are preferable. Suppose the first path contains 100,000 ohms, with a certain number of spark-gaps; the next arrester contains 1,000 ohms, with a few more gaps; the next one is 100 ohms, and still a few more gaps so as to require a higher voltage; then the next one is 10 ohms and still a few more gaps. If the designer of the lightning-arrester has sufficient confidence, the last path may contain still more gaps, and no resistance, as sketched in Fig. 3, diagramatically. There seems to me no reason why instead of separate spark-gaps for each path, the same spark-terminals could not be used for all, and the protective device built as sketched in Fig. 4. Even the same resistances may partly be used. Possibly we might go still further and connect on to

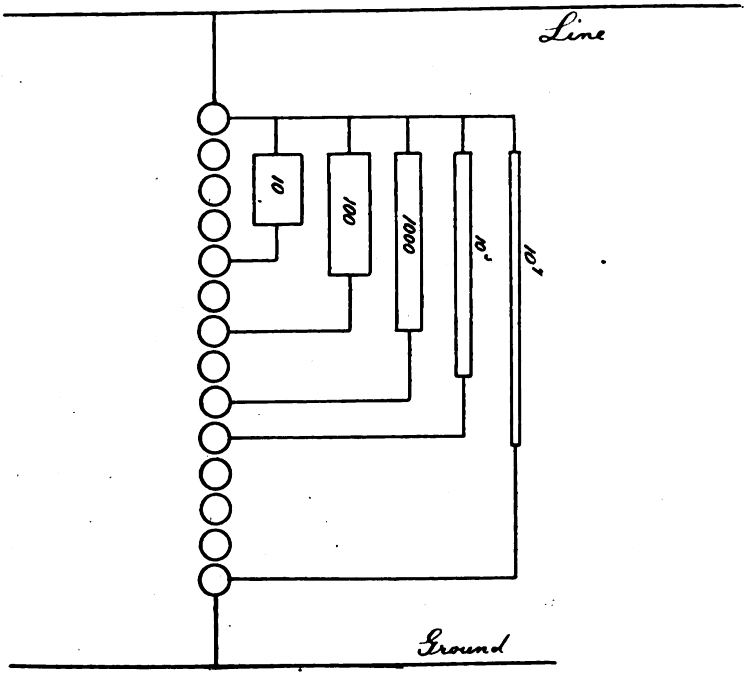

Fig. 4.

the next or to the ground line with a high resistance, so that a gradual accumulation of voltage can discharge steadily; this results in a very satisfactory arrangement for the discharge of lightning, because it would select the resistance according to the severity of the discharge and always use the least number of air-gaps and the highest resistance permissible by reason of the character of the discharge.

Percy H. Thomas: Somehow or other we do not seem to lose our interest in lightning-arresters, and I hope Mr. Mershon will not take away all of our discussion of theory, because if he does I do not know what we shall talk about.

I think a little more explanation of the method by which a series choke-coil protects the transformer winding is worth while. The point I want to bring out is that the concentration of potential on the outer turns results from the electrostatic capacity within the winding of the transformer. Suppose we have a transformer winding connected to earth on one side, and a static disturbance comes from the line; assuming that there is no capacity between the turns or to the ground in that winding, we will not get an uneven distribution of potential, severe at the line terminal and light at the other end, but a perfectly uniform distribution of potential throughout the winding, the same number of volts for each turn. Suppose we put a choke-coil between line and ground, and suppose the same disturbance to come from the line; as before we will get no concentration of potential, simply a distribution through the total winding of the transformer and the series coil; and each unit of induction will have the same voltage impressed upon it. Suppose, on the other hand, we have the actual case occuring in practice; that is, a winding with electrostatic capacity between each turn and ground and between adjacent turns (the latter having very much the same effect as the former); the capacity of each turn may then be considered as equivalent to a small condenser. Before the discharge from the line reaches the first of these condensers, the potential of the corresponding turn remains practically zero and there will be no change until the discharge from the line has flowed from the terminal to this first condenser, as Dr. Steinmetz has explained; and for a brief instant of time full potential is impressed between the terminal and this point. Then, as the charge penetrates, this potential is distributed on more and more turns. Suppose we assume *A* in Fig. 1 to be the line end of the transformer winding, and that the other end *B* is connected to ground. Then, in the first case where there is no capacity in the winding and no series coil, the maximum strains will be shown by Curve *I*, in which is plotted as ordinates the maximum potential which will be found on each turn. The resultant curve will be practically a straight line.

In the case in which we have capacity in the winding, however, and no series choke-coil, the curve of maximum potential between turns is shown by Curve II. Taking the case in which the winding has no capacity, and a series choke-coil is introduced at the point *C*, the distribution of potential will be as shown in Curve III, where each unit of inductance receives the same impressed voltage. In the case where the winding contains inductance and we have a series choke-coil, as usually met with in practice, we have a distribution of the potential as shown in Curve IV. The effect of the choke-coil is thus seen, in practice, to be the reducing of the maximum strain on the first turns only.

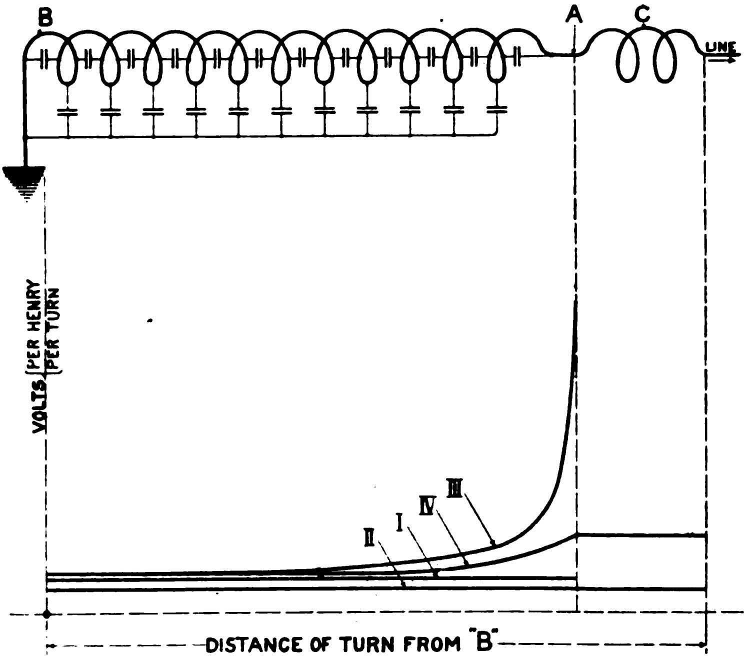

Fig. 1.

Of course the condition which determines how much potential will be impressed on the outer turns of the winding is the rate at which the charge penetrates the coil, and is controlled just as much by the capacity of the winding as by its inductance. The greater the inductance and the greater the capacity the slower will the discharge penetrate and the greater will be the concentration of potential.

I think it will generally be admitted that one given value of inductance in a series choke-coil will not be suitable for protecting all sizes and types of transformers.

Mr. Jackson has brought out an interesting point: that a condenser which is stretched out over a long distance; that is. having distributed inductance and capacity, as a transmission line, charged to a given potential, cannot produce during discharge more than a certain current, and that using a definite resistance in series with such a discharge would always produce a potential proportional to the potential to which the line was previously charged. This condition, which is not true of a condenser where there is not a uniform distribution of capacity and inductance, is analogous to the discharge of water from a long trough or canal of uniform cross-section, in which case when once started the liquid contents would flow out at the mouth at a constant rate, neglecting resistance losses. However, it is hardly safe to apply this conclusion to a practical transmission line, since we may not have one but several lines discharging through the arrester at once, and since we may have a direct lightning discharge passing to ground which will, of course, be controlled as regards its current strength by considerations other than line capacity.

I wish to call your attention again to another system of lightning protection, differing from the arrangement suggested by Mr. Mershon. Suppose we have a transmission line and have standard lightning-arrester apparatus of a type capable of caring for ordinary discharges continuously and without renewal. We may then add at some point, possibly between 1 and 5 miles from each station, a number of fuses in parallel connected between line and ground in series with a spark-gap, each fuse having an addition a gap of its own. We then have an arrangement which will not only care for ordinary disturbances without attention or renewing of apparatus, through the arresters at the stations, but also for relieving severe discharges or passing direct strokes to earth through one of the fuses, and thus interrupting the generator current. The use of several fuses and series air-gaps insures that a number of severe discharges can occur without leaving the line unprotected. These fuses can also be easily arranged to be renewed while voltage remains on the line.

This system of protection is brought up at this meeting on account of the tests reported by Mr. Jackson, which indicate that a fine wire inclosed in a tube opens the circuit very quickly —in this case at the end of the first alternation—without rise of potential and without opening circuit-breakers, and presumably without disturbing synchronous apparatus. This result, if substantiated by later experience, as seems very probable, is of the greatest importance, as it eliminates one of the chief presumptive difficulties of fuse arresters: namely, the interruption of service from temporary short-circuit on the line I suggest, however, the use of a German silver wire in place of the fine copper wire, as this will blow at a smaller current.

The electrolytic arrester is, of course, the item of greatest interest in Mr. Jackson's paper. There seems to be a general impression that this will work out satisfactorily and will eliminate a great many of our lightning-arrester troubles, both theoretical and practical.

E. E. F. Creighton: In the matter of equivalent needle-gap of apparatus, resistance, etc., the mysteries are gradually clearing away. In measuring the equivalent needle-gap of a resistance there are a number of factors involved which give variations. The equivalent needle-gaps of rods in series and parallel are given below:

The *G* gap on the static machine was set at 4 in., the electrodes on the static machine were 1.4 in. in diameter. The inner coatings of three one-gallon Leyden jars were connected to each terminal of the machine, and the outer coatings of each set were connected to the resistance terminals. The equivalent needle-gap of three rods (750 ohms) was 1.59 in. With another equal resistance laid in parallel, the equivalent needle-gap was 1.27 in. With the third equal resistance laid in parallel, the equivalent needle-gap was 1.09 in. With the resistance short circuited, the equivalent needle-gap was 0.15 in. If the three values of equivalent needle-gap of the three resistances are plotted, there is a proportionality which approaches a straight line. If we take into account the impedance in the circuit, we do not in this case get the concordant values shown later. There is every reason to believe that the same laws apply to a needle-gap used to measure voltage as apply to meters. In this case we are attempting to measure the impedance of a circuit 16 in. long with a needle-gap connected to leads which are more than three times as long. therefore we may scarcely expect to get correct values of the inductive drop across the 16 in. Furthermore, it requires a certain time to elapse after the potential is applied to the needle-gap before the gap begins to spark. If we put the needle-gap, as an instrument of measure, under better conditions of operation; that is, make the needle-gap circuit of less inductance than the circuit to be measured, it gives, at least in most cases, reasonably good results. Following is given the relation of the equivalent needle-gap of resistance made up in two ways:

1. As a sample rod of 250 ohms; 2. As seven rods in parallel and seven sets in series, making a total of 250 ohms. The equivalent needle-gap of the single rod was 0.47 in. (*G*-1 in). The equivalent needle-gap of the 49 rods was 0.86 in. The circuit composed of the 49 rods was necessarilly very much longer than that of a single rod, consequently a short-circuiting wire was laid over the same path and the equivalent needle-gap taken of the inductance. The value was 0.6 in. It will be seen that the equivalent needle-gap of the inductance and the equivalent needle-gap of the resistance will combine vectorially to make 88% of equivalent needle-gap of the impedance of the 49 rods. This error of 12% can be accounted for.

The same set of resistances was tested with a machine gap of $G = 7$ in. We obtained the following equivalent needle-gaps:

250 ohms in a single rod,	0.59 in.
250 ohms in 49 rods,	1.35 "
A copper wire in place of the 49 rods,	0 95 "

The combination of the resistance, 0.59 in. and inductance 0.95 in. vectorially gave 1.12 in. for the equivalent needle-gap of the 49 rods instead of 1.35 in. Again, the conclusion is that the discrepancy is within the degere of accuracy of measurement. These rods were made of standard composition with carborundum as a base. The resistance seems to have the same parelleling properties as metallic resistance. In fact, the same ohmic resistance of either non-metallic rods or metal wire gives the same equivalent needle-gap. There is a case, however, where parallel resistances made up of non-metallic composition will not have the paralleling properties. This kind of resistance may be placed in the category of coherers. If the substance of the resistance is composed of particles which are normally in separation and a static spark takes place, the particles cohere along a definite line and suddenly reduce the resistance to a comparatively low value. If the resistance is sufficiently reduced or the quantity of electricity is sufficiently small, the coherer thread of contacts relieves the potential and there is no tendency for the material to break down in any other line. Under these circumstances, placing a parallel resistance in circuit will not affect the equivalent needle-gap.

As a matter of comparison, the equivalent needle-gaps are given herewith for rods of higher resistance. In each case the machine gap, G, was 4 in. The length of the rods in the following test was 8.5 in. The equivalent needle-gap of one 3200-ohm rod was 1.52 in. The equivalent needle-gap of two of these rods in parallel was 1.14 in. It should be noted that the equivalent needle-gap of this 3200-ohm rod is less than the equivalent needle-gap of 750 ohms, due to the fact that the three rods making up the 750 ohms gave a longer length of circuit than the one rod of 3200 ohms.

The equivalent needle-gap of one 220,000-ohm rod was 2.15 in. The equivalent needle-gap of two of these rods in parallel was 1.79 in. It should be noted in this test that the resistance of the rod as compared to the inductance of the rod is becoming predominant.

Since these results can be explained by conditions of the inductance, capacity, and the method of measurement, it would seem that an equivalent needle-gap taken under any other condition need only have all the conditions given to make it intelligible. If the frequency of the circuit is lowered the inductance factor in the above tests becomes more negligible.

The speaker has been working for several years on electrolyte cells, especially in their application to lightning-arresters. Two years ago one of these arresters was installed for test on a line during a short period, and last year we had an aluminum cell arrester on a 33,000-volt line during practically the whole lightning season. The speaker was scheduled last year to read a paper on this subject before the Institute, but it was thought advisable to put the arrester in commercial form with the experience of a season back of it before describing it. There is much to be said in its favor. We have collected a considerable amount of experimental data concerning its operation which we hope to present at the March meeting. These cells can be so made that the resistance above the critical voltage will be but $\frac{1}{1000}$ of the resistance below the critical voltage. In other words, a cell has a high resistance for normal potential, but a low resistance for potentials much above the normal. It has been our practice to install the arrester with its critical potential about 25% above normal. The current that this cell will discharge without increasing the potential to a dangerous value depends entirely upon the construction.

Below will be found some information regarding screening, chosen from tests on the multigap arrester. There were 190 $\frac{1}{32}$-in. gaps in series. Without a screen on the multigap arrester, the spark-potential on a 60-cycle circuit was 68 kv. With a screen around the multigap arrester, the spark potential dropped to 60.4 kv. With one terminal permanently grounded, the spark potential was 47.5 kv. without a screen; with a screen the spark potential rose to 53.9 kv. With one terminal arcing to ground and no screen, the spark potential was between 34 and 36 kv. Under the same conditions, with a screen the spark potential was between 40 and 43 kv. It will be seen from these tests that the tendency is to make the spark potential more uniform for all conditions, but the screen does not entirely accomplish the result. The equivalent needle-gap with an impressed frequency of three million was then taken with the following results:

The equivalent needle-gap with the screen was 2.45 in.; the equivalent needle-gap without the screen was 2.67 in. The sum of the 190 series gaps is 6 in. The two halves of the arrester were connected by a wire of considerable length which makes the equivalent needle-gap higher than that of the normal installation.

In regard to the form of the potential wave. I presume that the direction of movement in Fig. 8 is from right to left and that a current transformer was used in getting the current record, but I cannot understand why the potential wave is all on one side of the zero value. Did not this oscillograph have a very low natural period of vibration? In Fig. 9 I note again that the deflections of the potential wave are greater on one side of the zero than on the other side and that the generator wave of potential had already reached a considerable value before the switch was closed.

In Fig. 8 the oscillogram shows that the current apparently reversed in direction and then came gradually back to zero. Experience demonstrates that the current will continue to flow during most, at least, of the second half-cycle if it once gets started in the reversed direction. The false record of the oscillogram is due to the use of a current transformer. The magnetic leakage in the transformer prevents the current in the oscillograph rising to its true maximum value. The decreasing current is less sudden, the magnetic leakage less and therefore the deflection is carried across the zero and returns along a logarithmic curve to zero.

H. B. Alverson: As the testing of lightning-arresters comes at the operating end, I can merely speak of certain results obtained in stations having 700- to 1200-kw. circuits, with a station capacity of 3,000 to 6,000 kw., with standard forms of lightning-arresters. The experience extended over a period of several years. It was soon found that arresters without series resistance on these circuits were of no value. The standard forms of lightning-arresters were used under ordinary conditions, with care and inspection, the limiting resistance producing a condition that gives operating results approaching continuous service. We have one of our stations equipped with choke-coils and low-equivalent arresters. With this outfit no interruption to the service has occurred; whether this covers all conditions or not of course we cannot tell. As Dr. Steinmetz has said, we cannot obtain arresters that will cover every condition, but it appears to me that on the lower voltages there is apparatus with which results may be obtained which will answer all purposes.

As I read it, this paper gives a method of determining the proper choke-coil to be used for any particular apparatus. With that data it should not be a very difficult matter to obtain proper proportions of apparatus so as to avoid suffering any severe interruptions except in extraordinary cases.

P. M. Lincoln: The collection of data on this subject of lightning protection is one of the most difficult with which the electrical engineer has to deal. It is difficult on account of th impossibility of observing what takes place in practice. It is impossible to tell the exact strength of the blow of the lghtning force in any given case, and it is almost impossible to tell what its results are on account of the lack of observers at the time the thing happens and the varying tales one gets from casual observers after the thing happens. As I look at it, there are three methods by which we can collect data on the general subject. One is that just mentioned; viz., the observation of lightning phenomena themselves. This is unsatisfactory, for the reasons just stated. Although it is impossible, or difficult. rather, to judge of the reason why certain protective apparatus fails or succeeds in actual practice, still on its results in actual practice must depend the final judgment as to the value of that apparatus.

The second method of obtaining data on this subject is that of pure reason. In that category I place the first part of the paper read this evening, and also the interesting arrester arrangement which Mr. Mershon has just described. I would also place in the same category the very interesting exposition which Mr. Steinmetz has given us in regard to when a choke-coil is not a choke-coil. These things I would place under the head of pure reasoning on this subject, and we can get a good deal of information in that way.

The third way is to manufacture our own lightning and discharge it through set conditions in certain circuits, and by varying the conditions which obtain in the circuits, derive the information sought for. By creating our own artificial lightning and discharging it through given conditions, and making observations, by that method we can gain our most reliable data. That is the method pursued in the historical experiments by Oliver Lodge, as well as those pursued later by Mr. Wurts and still later by Mr. Thomas and others.

One more point, and that is in designing lightning apparatus we have two things to protect; one, the protection of the apparatus in the circuit; the other, the protection of the service. A simple spark-gap, nothing in series with it, is undoubtedly a most perfect protection to the apparatus. It allows the accumulated charge to get off the line, but at the same time it allows the dynamo current to follow and thereby interrupt the service, unless there is some arc-interrupting device. I think that these two things should be kept quite distinct: protection of the apparatus and the protection of the service. Most operating engineers will be willing to sacrifice some apparatus to save the service.

Ralph D. Mershon: Referring to the suggestions made by Dr. Steinmetz relatively to using a single resistance, I have preferred not to do this because it seems to me an advantage to have several paths, thus reducing the inductance as well as the resistance of the combined path to ground.

One reason for not using the number of gaps shunted in the way he described is that my experience with a series of gaps has not been a very happy one, due to the peculiar distribution of potential over these gaps by reason of capacity effects. I prefer something like a horn arrester which is not easily burned up, and is not subject to the uncertainties to which a series of gaps are liable. I am especially in favor of the horn arrester because it can be put out of doors; whereas a series of discharge gaps is not well suited to this.

I think that fuses on the line would not be effective in protecting station apparatus, judging from some things which have happened from time to time on transmission lines under construction. I have known of cases where a line in the course of construction, with the line conductor grounded at the point where the construction work left off, has been struck by lightning which, instead of going a mile along the line conductors to ground, has preferred to smash through insulators, presumably in the neighborhood of the point where the disturbance originated. I am sure that fuses, in order to protect the station, would have to be at closer intervals than those suggested by Mr. Thomas.

R. P. Jackson: Mr Mershon asks about Fig. 4. In that case the static disturbances were impressed upon both ends of the transformer. I left off the other end of the curve, as it was a duplicate of the end shown. We got no record different from the end which is shown. As to what the effect of the disturbance on one end would otherwise have been on the other we cannot tell; but tests have been made with transformer coils, with iron and without iron, showing no material difference, in choking effect, etc.

In regard to oil choke-coils, and the closer spacing of the turns, another point I did not mention was that this choke effect is not directly a function of its total inductance, but of its inductance per unit length; and naturally a coil which could be made more compact and have greater inductance per unit length of wire would have a greater reflecting effect. It is true, as Mr. Steinmetz pointed out, the capacity effect would come in, and a coil would be ineffective for very high frequency and very low frequency, but there is a wide range which appears to include most lightning disturbances which a choke-coil will handle.

Regarding the 400 ohms as a critical resistance, it was not meant that this was the only permissible resistance without any question whatever. It was a value which, under the conditions given, would just eliminate a rise of potential and reflection at the lead of the apparatus, meaning that lower resistances were desirable, if possible. Therefore, from that calculation it appeared to be that 100 ohms, or something in that region would be more desirable than anything above it. It would not mean that 1,000 ohms would not do any good, but that it would do so little good that great effort should be made to keep below the 400 ohms, because, under the conditions indicated, using 1,000 ohms ,while there is some discharge, there is still a rise of potential and reflection which will do harm. While the rise of potential is not the same for any resistance whatever, still it would be there to some degree; 400 ohms would prevent rise of the deflection, but still give a rise equal to that of the original incoming wave, while with zero resistance there would be no potential whatever existing there. What Mr. Thomas says about parallel lines requiring lower resistance is perfectly true.

In regard to the oscillograms, I did not operate the oscillograph at the time the records were taken, and I cannot say why the one on Fig. 8 is not symmetrical, but any one who has worked with an oscillograph knows that they do become erratic at times and deviate considerably, probably due to static influences.

This effect is not so noticeable on Fig. 9, but still the curve is somewhat distorted, due to some lack of adjustment in the oscillograph, or failure to ground the frame.

J. F. Vaughan (by letter): In view of recent progress made in special devices for the protection of lines and apparatus there seems to be good prospect of accomplishing proper protection against ordinary disturbances due directly to internal or induced by external causes. Little attention, however, has been given to the possibility of protecting lines against direct lightning stroke. It is unreasonable to expect to provide sufficient line insulation to prevent such a stroke from going to ground, or sufficiently frequent arresters safely to carry the excessive charge to ground. Why not divert such strokes from the lines? Lightning rods on the line poles and overhead grounded wires have been of some value in preventing damage to lines and poles. Why not go a step farther and provide entirely separate paths to ground by means of lightning rods mounted on separate poles well above and at one side of the line. With this in view, the 50,000-volt Taylor's Falls transmission line in Minnesota, in addition to a number of other devices, was protected last summer for two miles through the most exposed region by poles at the side of the line carrying rods 25 ft. above the upper transmission wire.

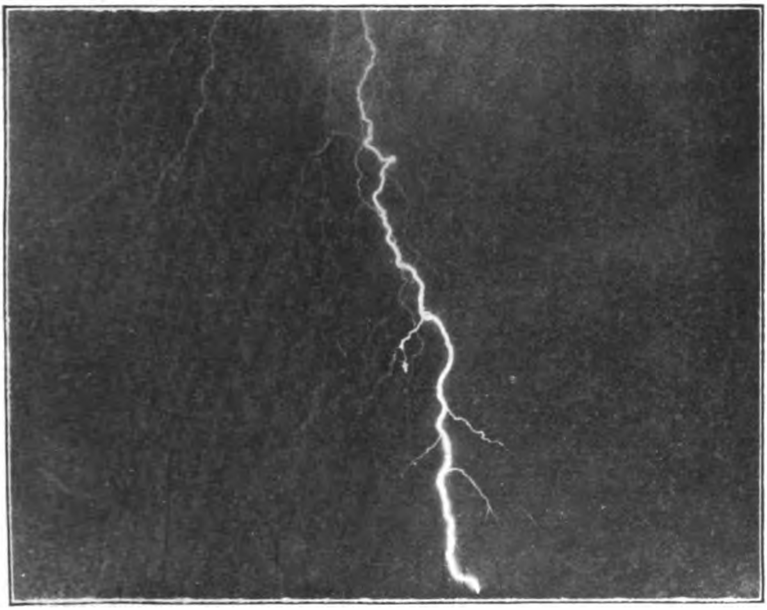

FIG. 1.

Although the storms last summer were unusually few and light, the photograph of one direct stroke to earth shows the main discharge branching off into many secondary discharges like an inverted tree, covering an area of ground of probably over a mile in diameter, indicating clearly that the territory affected was not restricted to the immediate vicinity of the bolt. It is interesting to note that while six transmission line poles in different parts of the line were splintered the previous summer before any wire was strung, last summer several of the lightning-rod poles showed punctured tell-tale papers inserted in their ground connections, one puncture indicating a heavy discharge to ground, while the line itself, though not in operation, did not suffer.

A. Henry Pikler (by letter): The present paper, it seems to me, although its title in general refers to lightning protective apparatus, deals in reality with such elements of it as are protective not against lightning directly, but rather against its secondary effect—induced high potentials; still more efficiently against surges due to short circuits, sudden and great changes of the line current. Furthermore, this apparatus is suitable to protect only particular points of an electric power transmission equipment—namely, those located in the power house or in the sub-station and not the transmission line.

In discussing the devices brought forward in the paper, I shall restrict myself to the choke-coil. Of late the choke-coil appears to have been much neglected. I have seen large power installations in connection with a 35,000-volt, 30-mile transmission line, made by one of the leading manfacturing companies of the country, where the choke-coil was omitted. The consequence was that during lightning storms, or, in the case of grounds, sudden changes of loads, short circuits, the ensuing surges ruptured the insulation of the main switches in the power house and grounded the line, although the lightning-arresters were discharging profusely.

In order to illustrate the powerful protection offered by a few turns receiving tremendous shocks directly, I want to mention that in the same power plant one of the little synchronizing transformers on the auxiliary bus-bars was connected up in the wrong way and when two transmission lines were to be parallelled, this was done in full oposition of the operating generators. A tremendous short circuit and rise of potential was the result and almost all the transformers broke down. Upon investigation it was found that only the very first turns of the end-coils were punctured through many small holes. It will be interesting to note that these end-coils had very heavy insulation on them, (also the end-turns were extra heavily insulated) sufficient to stand about 100,000 volts (though they were not at all intended to be choke-coils), whereas the other coils, many in number, were almost bare. These latter were entirely uninjured.

I was very much surprised to hear Mr. Mershon, the chairman of the High-Tension Transmission Committee, recommend the use of the first few turns of the transformer as a choke-coil by placing extra heavy insulation on them, thus saving the expense of an extra choke-coil. While theoretically this seems plausible, from the practical standpoint I most decidedly disagree with him. The duty of the protective apparatus is to save from injury the vital elements of a transmission equipment, even at the cost of life of the protective apparatus. This is necessary for two reasons: to avoid interruption of the service, and to save the more expensive power station equipment from breakdowns and burn-outs.

To have the choke-coil form the internal part of the transformer would mean to provoke just this trouble. There exists no commercial insulation or method of insulating that would save the choke-coil from a flash-over and ensuing burn-out between adjacent layers and turns, if the relation between inductance and capacity of coil and the periodicity of the disturbance is such as to cause resonance. Such and similar disturbances would mean to cut out that transformer and cripple the service for some time. Besides this, it means damaging and repairing a piece of apparatus worth several thousands of dollars, whereas if the choke-coil is made independent of the transformer it means only the damage of the choke-coil, worth perhaps a few hundred dollars.

Furthermore, from the standpoint of the designing engineer I do not consider it reasonable to have two pieces of apparatus, serving different purposes and involving entirely different methods of calculation, design, and manufacture combined in one. Both would suffer in the end, the transformer as well as the choke-coil. At the same time I do believe and strongly recommend the insulating of the first few turns next to the line with special care and precaution on every piece of apparatus, but I would like to see the choke-coil in series with it. On high-voltage induction motors operating at 5,000 volts and above, break-downs used to be very frequent, and there seemed to be no insulation good enough to resist potential rises due to sudden variations in load, etc.; the choke-coil was put in series with the terminals, and the trouble was eliminated at once.

H. W. Buck (by letter): The tendency of this paper and its discussion, which is common in the treatment of lightning disturbances, is to regard the problem solely from the standpoint of the mathematical theory of oscillations. This is undoubtedly wise to a certain extent, but there are very important lightning troubles which lie quite outside the realm of calculation. I refer particularly to direct strokes upon a transmission line from lightning bolts of great violence. Here the problem before the engineer might be considered more one in fortifications than in oscillations or surges. There are many discharges which take place in thunderstorms between clouds and earth which apparently are not only of very high potential but also of very large current volume. Trees and poles are sometimes completely shattered by such strokes. The explosive violence with which wood-fibre flies to pieces at such times seems only explicable on the theory that there is sufficient current to cause either instantaneous evaporization of the juices in the wood and consequent expansive force, or else the immediate expansion of the gases held in the pores of the wood. In either case the volume of current must be very large, and the ordinary lightning-arrester resistances used for the discharge of transmission lines is entirely inadequate. My feeling is that the electrolytic arrester described in the paper, if selected for the ground path of one of the above lightning bolts, would meet much the same fate as that of the tree.

The most promising system of protection against direct strokes on the line seems to be that of the overhead ground wire, or preferably a grounded network supported on the transmission poles or towers above the conductors. Such a system if properly installed and grounded at every support should afford almost complete protection against the striking of transmission conductors or insulators. If more than one ground shield wire is used, and the two or more wires are connected together electrically at frequent intervals, a further protection is provided, at least part. by this short-circuiting shield against the induced disturbances in the conductors from neighboring lightning discharges.

There is another source of disturbance from lightning which is not usually referred to in discussions of lightning troubles. I have known of a number of instances where direct strokes upon objects such as trees immediately adjacent to a line have been followed by a simultaneous short-circuit between phases on the transmission line at that point. Such action may be explained on the theory that the air surrounding the conductors becomes ionized and conducting by the influence of the stroke near by. Those who have handled high-voltage switches without barriers between them have observed how easily a short-circuit is started in a similar way by the influence of a neighboring arc. Lightning trouble of this kind cannot be prevented by the ordinary type of ground-discharge arrester.

Deductions as to the suitability of various types of lightning-arresters from the experiences of individuals are very misleading. One man who has had no lightning trouble during a season attributes his success to the particular type of arrester he has installed in his plant. His success quite possibly might have been the same with no arrester at all on his lines. Another operator whose arresters have been completely destroyed, probably by some direct stroke on the line, discards the type as useless although it may have successfully taken care of all ordinary disturbances.

EXPLANATION.

The following article is an " Introduction " to a discussion to take place at a meeting of the Institute in the Auditorium of the Engineers' Building, 33 West Thirty-ninth Street, New York, Friday, **March 22, 1907,** at 8 p.m. It is not intended to be a formal or complete paper, but to serve merely as a basis or framework for discussion on the subject with which it deals. All those connected with the Institute and desiring to take part in this discussion may do so by being present at the meeting, or if this is not possible by sending in a written " Contribution."

In contributing to a discussion, whether verbally or in writing, it is requested that the matter under discussion be taken up under the several subdivisions and in the order made use of in the Introduction, and that following the treatment of these subdivisions there be introduced any other matter which the contributor may deem advisable. When the contributions are made by mail on more than one of the topics under consideration at the same meeting, it is requested that the several contributions be embodied in separate letters.

Contributions will be read at the meeting for which they are intended either in full, in abstract, or as part of a general statement giving a summary of views of those taking the same position in the matter under discussion.

It should be borne in mind that the Introduction is written in order to provoke discussion, and that there should be no hesitancy in attacking if it does not agree with the opinions of the contributor. On the other hand, if the contributor agrees with the matter of the introductions, either in whole or in part, he should state the fact.

It should also be borne in mind that the principal object of this scheme is to enable and encourage those not in a position to attend meetings to take part in a discussion. If one does not feel himself qualified to discuss certain parts of an Introduction, but is able to discuss other parts, it is to be hoped he will contribute to the latter.

Contributions to the discussion of this paper should be mailed to *Ralph D. Mershon, Chairman Transmission Committee,* 60 *Wall St., New York, N. Y.,* so that they will be received not later than **March 18, 1907.**

A paper to be presented at a Special Meeting of the American Institute of Electrical Engineers, New York, March 22, 1907.

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(*Subject to final revision for the Transactions.*)

MOTOR-GENERATORS *vs.* SYNCHRONOUS CONVERTERS

WITH SPECIAL REFERENCE TO OPERATION ON LONG-DISTANCE TRANSMISSION LINES

BY P. M. LINCOLN

GENERAL

The particular problem to be considered in this discussion is the following: wanted, direct-current power of approximately constant voltage; for instance, for railways 500 to 700 volts, for an incandescent lighting system, 100 to 275 volts, for an electrolytic process, any direct-current voltage. Given as a source of power, a long-distance alternating-current transmission system, which may be either 25 or 60 cycles, may have a varying voltage at point of delivery, may have the variation occur either on account of the load taken by our particular station or independent thereof and may have a somewhat variable frequency. Problem, what shall be used for making the desired transformation; synchronous converters? motor-generator sets with synchronous motors? or motor-generator sets with induction motors?

In this discussion a comparison will be made between these methods in regard to the following points, these points being placed, in the opinion of the writer, in the order of their relative importance.

1. Reliability.
2. Voltage regulation.
3. Corrective effect.
4. Efficiency.
5. Cost.
6. Parallel operation.
7. Starting.

These points will be taken up in the order named. As a matter of simplification, it will be assumed that the line voltage is too high for a revolving machine and must be transformed before utilizing.

1. RELIABILITY.

In this connection, the term "reliability" is taken to mean simply freedom from accident, or, in other words, capability of performing normal functions continuously without interruption. Without this element of reliability, it is evident that no plan of transformation can be a success. To those charged with the responsibility of the operation of such a plant, there will be no question but that this feature deserves the first place.

As to reliability, it is evident that the synchronous converter has a very decided advantage in that there is only one machine to get out of order, whereas either of the others involves two. Further, we are forced to use a low voltage on the synchronous converter so that its insulation is normally called upon to stand a maximum of not more than 700 volts; whereas with the motor-generator sets other conditions may dictate a very much higher motor voltage, and, therefore, a lower factor of safety in insulation. Both the synchronous converter and the synchronous motor-generator set suffer the disadvantage that a momentary removal of the voltage from their terminals—a short-circuit on the transmission line for instance—will cause them to drop out of step and make it necessary to start them over again. In this respect the induction motor-generator has an advantage in that it will resume operation automatically after such a temporary cessation of incoming power.

As to "bucking," this is a fault that is more commonly attributed to synchronous converters than to direct-current generators, but the reason for it is that the converter is more widely used under conditions that will cause "bucking" than is the direct-current generator. The usual cause of "bucking" is the sudden occurrence and removal of heavy overloads; as, for instance, when a circuit-breaker blows. The ideal conditions for this occur on the average interurban road, where the sub-stations are relatively small compared with the maximum loads carried. A direct-current generator of the same size and exposed to the same conditions would probably give rise to about the same amount of "bucking." Exception is made in the case of the 60-cycle converter, which is admittedly somewhat more sensitive in this respect than the 25-cycle converter, chiefly on account of its necessarily short distance between brushes.

As a relative comparison of the reliability of the methods under consideration in railway work, the following is advanced as a personal opinion. The number given indicates the relative number of hours that the apparatus would be out of service within a given time on account of defects inherent in the apparatus.

25-cycle synchronous converter	10 hours.
Induction motor-generator	14 "
Synchronous motor-generator	17 "

2. VOLTAGE REGULATION

The term " voltage regulation " here will be confined to the changes that may take place in the direct-current voltage. The term embraces at least three distinct features:

a. Automatic change in voltage with change in load.

b. Ability to adjust the initial voltage.

c. Variations in direct-current voltage with variations in incoming line voltage and frequency.

Automatic Change in Voltage with Change in Load. In this respect all methods under discussion are equal. Rising or drooping characteristics of an adjustable value can be obtained with either the synchronous converter or the direct-current generator. The converter suffers the disadvantage that the power-factor of the current supplied must vary with varying loads, whereas with the motor-generator sets the direct-current voltage compounding adjustment is independent of the alternating-current circuit. This point will be further discussed under subsequent headings.

Ability to Adjust the Initial Voltage. It is in this respect that the synchronous converter suffers its greatest handicap. In the motor-generator sets the direct-current voltage is absolutely independent of the incoming alternating-current power. With the synchronous converter, on the other hand, the only way to adjust the direct-current voltage is to make a proportionate adjustment of its alternating-current voltage. There are several methods of accomplishing this end, which may properly be discussed under this heading.

One method is to insert a reactance in the alternating-current circuit of the converter. By changing the field strength of the converter, adjustments of the voltage applied to the collector rings can be obtained within limits, depending upon the amount of reactance and available field adjustment. The disadvantage of this scheme is that the alternating-current voltage is thereby made interdependent upon the power-factor of the incoming alternating-current power, and that the high-tension line voltage is dependent upon the direct-current voltage adjustment to an extent depending upon the relative reactance in transmission line and in the local converter circuit.

Another method is to use an alternating-current booster having the same number of poles as the converter and mounted upon the same shaft. This is approaching motor-generator conditions, except that the generator involved has to take care of only a small percentage of the output of the set under consideration, and the range of voltage adjustment instead of being from zero to the required amount remains between limits depending upon the relative output of converter and booster. This really makes a more logical arrangement so far as initial voltage adjustment is concerned than the motor-generator, since adjustment down to zero is never required in practice. The maximum range of adjustment ever required is the range of incoming voltage fluctuations plus the initial range required.

Still another method is the use of taps on the transformer stepping down to the converter, or of an induction or other type of alternating-current voltage regulator. These in general have the same effect as the booster just described. It is outside the range of this paper to discuss their relative merits. The addition of any of these means of voltage regulation makes the converter equal to the motor-generator set as far as ability to adjust initial voltage is concerned.

Variations in Direct-current Voltage with Variations in Incoming Line Voltage and Frequency. The difference between the converter and the motor-generator set in this respect consists in the fact that the converter responds only to changes in the incoming voltage and the motor-generator only to changes in the incoming frequency. This last statement may be modified slightly by recognizing that the slip of the induction motor depends upon the voltage, but the normal variations of voltage are so small that this feature can be safely neglected. For a given percentage change in incoming line voltage, there will be an equal percentage change in the direct-current converter voltage. For a given percentage change in incoming line frequency there will be a greater percentage change, nearly double, in the direct-current voltage of a motor-generator set. However, changes in incoming line voltage will under normal conditions be much greater and sharper than those in frequency, so that in this respect the converter will probably suffer by comparison with the motor-generator.

There are cases where, on account of voltage regulation, a straight synchronous converter would be absolutely unusable as, for instance, where a steady direct-current voltage for lighting is desired and the voltage of the alternating-current supply is varying due to causes other than the direct-current load under consideration.

The conditions which dictate the choice between converters and motor-generators with respect to direct-current voltage regulation are so variable that no attempt will be made to give any estimate of relative merits in numerical values.

3. Corrective Effect

By " corrective effect " is meant in general the results that may be obtained in respect to the voltage regulation of a transmission line by means of a change in the power-factor of the current taken. Only the synchronous motor and the synchronous converter need to be considered, since the power-factor of the induction motor is not adjustable.

It is desirable in any transmission line,

a. That the voltage shall remain as nearly constant as possible independent of the variation of load, and

b. That the voltage shall be capable of adjustment within limits at the will of the operator at any point.

So far as corrective effect is concerned, the synchronous motor has a distinct advantage over the synchronous converter in that the corrective effects may be obtained without involving the direct-current voltage. In the converter the corrective effect and the direct-current voltage are interdependent. On the other hand, when a converter is adjusted for a rising direct-current voltage characteristic, the tendency is to correct, in part at least, for the transmission-line drop caused by its own load. Thus it tends to fulfil condition (*a*) stated above. The synchronous motor can be made to fulfil condition (*a*) to the same extent by causing the direct-current generator current to flow through series coils on the motor field.

As to condition (*b*), both converter and motor field can be so adjusted by hand as to accomplish this end, but in the case of the converter not without making a simultaneous adjustment in the direct-current voltage. In order to secure the same independence of action with converter as with synchronous motor, it is necessary to have some means of adjusting the converter alternating-current voltage independent of simultaneous power-factor adjustment; as, for instance, the synchronous booster or voltage regulator described under the previous heading.

There is another point of view that should be presented before dropping this subject. A sub-station using the apparatus under discussion may or may not be under the control of the transmission-line operator. If it is, then its corrective effect can be used as transmission line conditions may dictate. If it is not under his control, the possession of corrective effect may not only be of no advantage, but also a positive menace to the proper voltage regulation of the line. If it is not under his control, he is probably better off with the induction motor-generator set, since it is neutral and possesses no power of changing line voltage at the caprice of an uncontrolled individual.

From the standpoint of corrective effect, therefore, the synchronous motor-generator has decidedly the advantage over the straight. converter while the induction motor-generator is entirely neutral. No attempt will be made to give comparative numerical values since this depends, not only upon specific conditions, but also upon the point of view.

4. Efficiency

At the end of a transmission line power is usually sold by the kilowatt hour, or some other function that is proportional to it. The amount of the monthly bill will be proportional to the meter-reading, and the efficiency of the transformation therefore enters as a direct function in the cost of power. In this respect the converter has a decided advantage. It is a case of the losses in one machine as against those in two, and, moreover, the losses in the converter are somewhat less than in either element of the motor-generator set. The full-load efficiency of a converter of, say, 500 kw. capacity, may be put approximately at 95% the synchronous motor-generator set, 89%, and the induction motor-generator set, 88%. The all-day efficiency will be considerably less than the above. As a reasonable estimate of the all-day efficiency under about 75%

load, the following is submitted. In submitting these the writer has in mind units of 500 kw. capacity or thereabouts:

25-cycle synchronous converter	93%
Synchronous motor-generator	85%
Induction motor-generator	84%

The following calculation based on the above is somewhat surprising. Assume a station using a 500-kw. unit an average of 18 hr. per day at 75% average load. Assuming power to cost one cent per kilowatt-hour, the saving in power bill per year of converter over motor-generator is $2100.00. Capitalized at 6%, this represents $35,000.00. In other words, one could afford to pay $70.00 per kilowatt more for converters than for motor-generators.

5. Cost

In regard to cost, the synchronous converter has an immense advantage. Here again, as in efficiency, it is the cost of one machine against two; and the cost of the converter is not far different from that of each machine that goes to make up the motor-generator. An approximate idea of relative cost is given in the following:

Synchronous converter	60%
Synchronous motor-generator	100%
Induction motor-generator	100%

6. Parallel Operation

The two points to consider in parallel operation are:

a. Proper division of direct-current load between units.

b. Proper operation so far as alternating-current ends are concerned, such as freedom from "hunting," etc.

As to division of direct-current load, there is no question either on direct-current generator or converters. In fact, it is perfectly possible by proper adjustment to operate converters and motor-generator sets of both kinds all in multiple.

As to operation on the alternating-current ends, the induction motor-generator is the least liable to trouble, since "hunting" or "pumping" cannot take place on that type of machine. The synchronous motor and converter are on a par in regard to hunting. However, with the modern construction of synchronous machines, including as they do heavy dampers, there is so little probability of hunting that it may be entirely neglected. The only places in which hunting is apt to occur are in cases where antiquated generators are used and where the ohmic line drop is very high. Neither of these is apt to occur in practice.

7. STARTING

In starting the desirable features are:

a. Minimum draught of current from line of starting from alternating-current end.

b. Ease of synchronizing.

a. It is difficult to make any of the apparatus under discussion of such design that it will start readily from the alternating-current end. Good running characteristics invariably mean poor starting characteristics. The inherent starting characteristics of the synchronous motor and converter are bad on account of the large air-gap. The converter has the advantage of only having one-half the mass of the motor-generator to start. The induction motor-generator set has the advantage of better starting characteristics, but it suffers in comparison with the converter in having double the mass. If started from the collector rings, the converter suffers by liability of damage to commutator by burning and sparking. A draught of full-load current or less from the line is usually sufficient for starting any of the sets.

If it is essential to keep down starting current, a starting motor can be employed. In this case the converter again has the advantage of one half the mass as well as one-half the losses of the motor-generator set. The same advantage applies to starting from the direct-current end, but is partly off set in the converter by the shunting effect of the static transformers, if these be connected.

b. In synchronizing, the induction motor has a great advantage in not requiring synchronizing at all. As between the converter and the synchronous motor, the converter suffers the disadvantage of having a commutator connected to the winding being synchronized, and, therefore, liable to injury by careless manipulation.

Altogether, there is not much choice in the starting qualities of the three methods, but what there is would cause them to be arranged in the following order:

1. Induction motor-generator.
2. Synchronous converter.
3. Synchronous motor-generator.

SUMMARY

On three of the preceding seven counts; namely, 1, 4, and 5, the converter has a distinct advantage.

On one more, 6, all methods are taken as being on a par.

On the remaining three, 2, 3, and 7, one of the other methods has the advantage. In one of these, 7, the disadvantage of the converter is not marked. The converter's disadvantage on the other two largely disappears with the addition of a means of voltage regulation.

This analysis, therefore, would seem to indicate that there are but few cases where the motor-generator should be used in preference to the synchronous converter.

EXPLANATION.

The following article is an " Introduction" to a discussion to take place at a meeting of the Institute in the Auditorium of the Engineers' Building, 33 West Thirty-ninth Street, New York, Friday, **March 22, 1907,** at 8 p.m. It is not intended to be a formal or complete paper, but to serve merely as a basis or framework for discussion on the subject with which it deals. All those connected with the Institute and desiring to take part in this discussion may do so by being present at the meeting, or if this is not possible by sending in a written " Contribution."

In contributing to a discussion, whether verbally or in writing, it is requested that the matter under discussion be taken up under the several subdivisions and in the order made use of in the Introduction, and that following the treatment of these subdivisions there be introduced any other matter which the contributor may deem advisable. When the contributions are made by mail on more than one of the topics under consideration at the same meeting, it is requested that the several contributions be embodied in separate letters.

Contributions will be read at the meeting for which they are intended either in full, in abstract, or as part of a general statement giving a summary of views of those taking the same position in the matter under discussion.

It should be borne in mind that the Introduction is written in order to provoke discussion, and that there should be no hesitancy in attacking if it does not agree with the opinions of the contributor. On the other hand, if the contributor agrees with the matter of the introductions, either in whole or in part, he should state the fact.

It should also be borne in mind that the principal object of this scheme is to enable and encourage those not in a position to attend meetings to take part in a discussion. If one does nót feel himself qualified to discuss certain parts of an Introduction, but is able to discuss other parts, it is to be hoped he will contribute to the latter.

Contributions to the discussion of this paper should be mailed to *Ralph D. Mershon, Chairman Transmission Committee,* 60 *Wall St., New York, N. Y.,* so that they will be received not later than **March 18, 1907.**

A paper to be presented at a special meeting of the American Institute of Electrical Engineers, New York, March 22, 1907.

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INTRODUCTION TO DISCUSSION ON THE PRACTICABILITY OF LARGE GENERATORS WOUND FOR 20,000 VOLTS

BY B. A. BEHREND

With the increased capacity of individual units of alternating-current generators it is natural that the potential for which these generators are wound should be continually increased. It commends itself to limit the current capacity of generators, as the distribution and conduction of large currents from the generators to the switchboards is cumbersome and expensive. Historically, the increase in voltage with the increased capacity of individual units and of power plants may be briefly summarized. The Niagara generators of approximately 3500 kw. capacity, put into operation about ten years ago, were designed for 2200 volts. The 3500 kw. generators of the Metropolitan Street Railway Company, of New York, were designed for 6600 volts. The 5000-kw. generators installed in the stations of the Interborough Rapid Transit Company, in New York, were designed for 11,000 volts. The large generators for the Brooklyn Rapid Transit Company, of 7500 kw., were designed for 11,000 volts also.

The question of the importance of higher voltages in future plants cannot be discussed without reference to prime movers. The four types of prime mover which are likely to be of great importance in the immediate future are:

1. The hydraulic turbine.
2. The gas engine.
3. The reciprocating steam engine.
4. The steam turbine.

1. The field of the hydraulic turbine for large capacities, by which I mean capacities of 7500 kw. or above in individual units, is not likely to be of great importance at the present.

2. The gas engine has been successfully built for capacities up to 2000 kw. and while it has unquestionably a great future for greater capacities, nothing as yet has been done to allow the application of the gas engine in connection with electric generators of 7500 kw. or above.

3. The reciprocating steam engine still holds its own for small capacities, but for the capacities which we are here considering it has been superseded by the steam turbine.

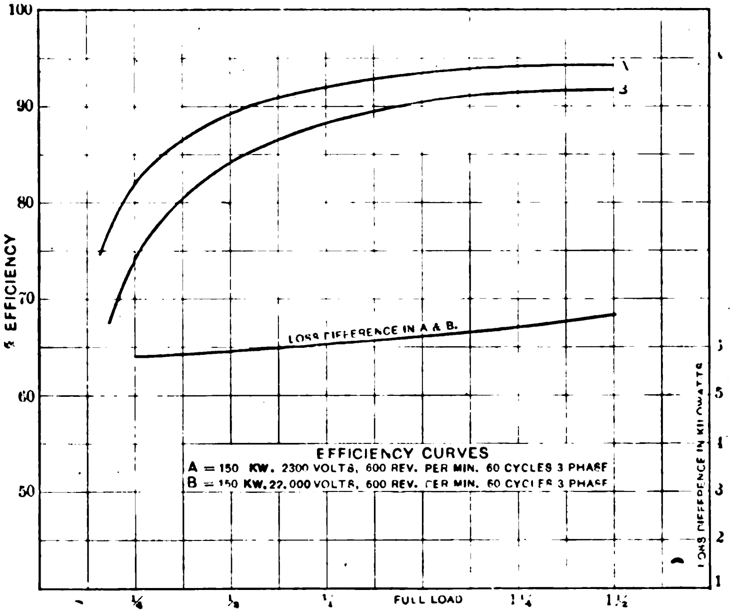

Fig. 1.

4. The steam turbine in its present condition is pre-eminently adapted to large individual capacities. I should consider a steam turbine of 7500 kw. a comparatively small unit, and I am firmly of the conviction that steam turbines of 10 000 kw. or 15,000 kw., and even of 25,000 kw. will, before long, be developed and put into successful operation.

In thus looking to the steam turbine as the prime mover for generators of large capacity, we have limited our sphere of inquiry to generators of large capacity and high speed;

namely, conditions as best fitted for the operation of steam turbines. The question of high voltage in generators of small capacity and driven by other prime movers than the steam turbine will be referred to in the concluding paragraph.

STEAM-TURBINE GENERATORS FOR LARGE CAPACITY, 7500 KW. TO 15,000 KW. AND ABOVE

The difficulties encountered in winding generators for potentials of 20,000 volts or 25,000 volts are primarily mechanical difficulties. A coil containing a large number of small wires does not make a very mechanical piece of work. It would, therefore, appear to me desirable for the reasons here mentioned and some others, that the individual coils should consist of as few conductors as possible and that these conductors should be of such size as to enable the making of mechanically and electrically strong coils. Let us take a concrete example. A certain 7500 kw. turbo-generator wound for 11,000 volts and operating at 750 rev. per min. at 25 cycles, has six conductors per slot. A 7500 kw. generator wound for 22,000 volts, if designed along similar lines, would have twelve conductors per slot. Increasing the capacity of the generator from 7500 kw. to 15,000 kw. would enable the generator to be designed with six conductors per slot, and the difficulty produced by the higher voltage would be that of insulating the coils for the higher potential against ground and against one another.

The insulation of the coils against ground is easier to obtain than against one another. The question of insulating the coils from one another is particularly difficult in turbo-generators on account of the crammed conditions of the winding space, but at the present state of the art it is possible to obtain the necessary insulation for 22,000 volts, although this can be done only with considerable expense. As soon as there will be a demand for large units wound for 22,000 volts, this demand will be met by machines carefully designed for these conditions.

The question of reliability of service is closely allied to that of quick repairs. It will be urged that not only is the danger of the breakdown of a 22,000-volt generator greater than that of a 11,000-volt generator, but also the repairs, consequent upon a breakdown, will be more difficult to make on the 22,000-volt generator. While this statement is perfectly true, a plan can readily be devised so as completely to defeat this argument. In a large power house in which a number of units of large capacity of the steam-turbine type are installed, the only rational way to make quick and satisfactory repairs consists in the carrying of spare parts. It will commend itself to the operators of power stations to carry a spare revolving field for one of these units and a complete set of spare armature coils. It must be insisted upon that the armature coils of these high-potential generators can readily be replaced, and, unless the machines are designed to permit this, it would be necessary even to carry a spare stator completely wound, which would be almost equivalent to having a spare unit in the power house.

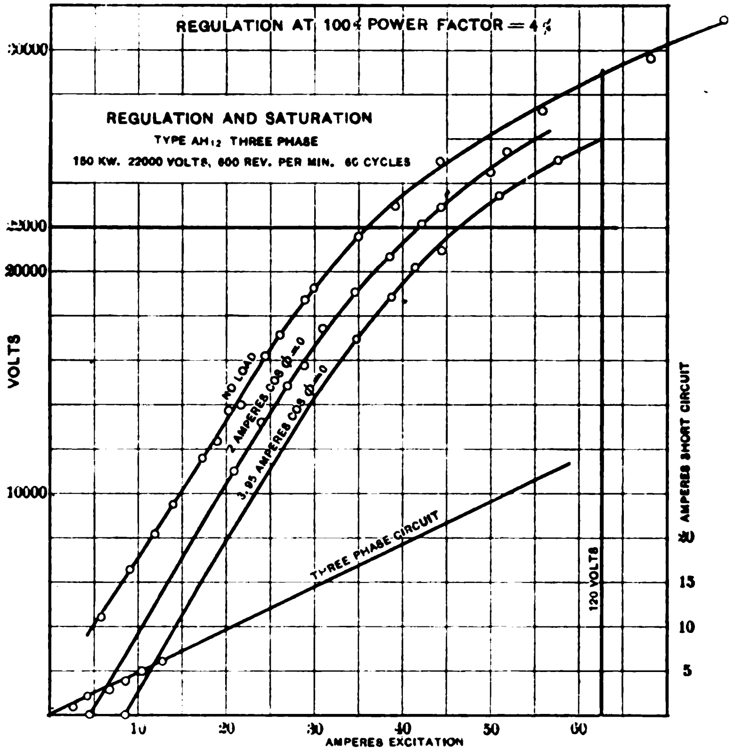

FIG. 2.

ECONOMY OBTAINED BY THE USE OF GENERATORS WOUND DIRECTLY FOR 20,000 VOLTS

The chief gains obtained by winding generators of large capacity directly for the high potential required for distribution consist in the simplification of the power plant and, probably, in a slightly reduced first cost. The question of reduced cost should certainly be considered a very minor factor, as reliability of service should be the criterion either in favor of, or against, the adoption of generators wound directly for high potential. Calculations of relative cost are here omitted on that account.

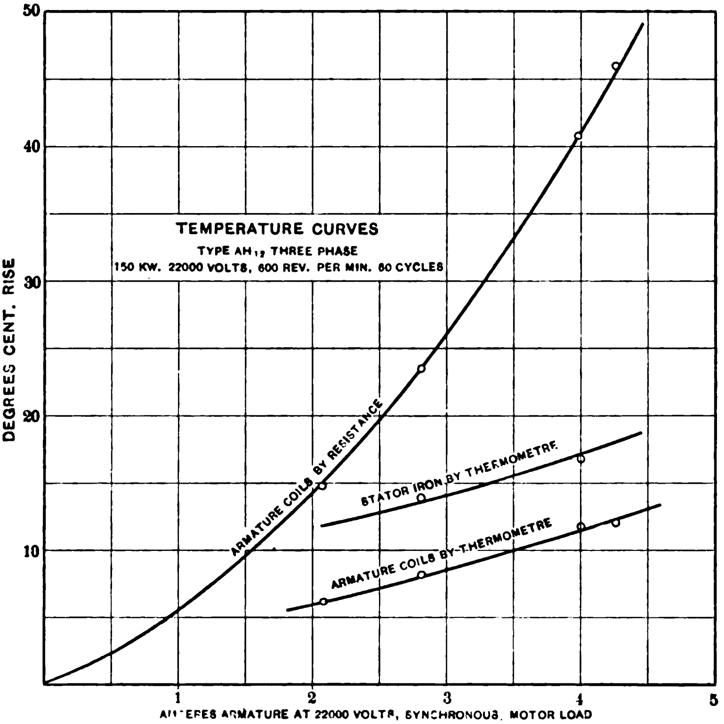

FIG. 3.

GENERATORS, REGARDLESS OF SIZE, FOR 20,000 VOLTS

For the sake of ascertaining the feasibility of insulating coils for 25,000 volts, the writer has had in operation a 150-kw. generator wound for 25,000 volts, 60 cycles, 600 rev. per min. This generator has been in operation for months, operating day and night under full load. Regulation curves and other data are illustrated in the accompanying diagrams. There is no doubt that there may be a limited field for units of small capacity wound for potentials above 11,000 volts, and the object of this paper is to call to the attention of the engineering profession the feasibility of generators of as small capacity as 150 kw., being wound for as high a potential as 25,000 volts. That the regulation, the heating, and the efficiency of this machine are very satisfactory is amply shown by the curves accompanying this paper. Should such machines be used in the future, it must always be insisted upon that the exchange of coils can readily be effected. In the 150-kw. generator referred to in this paper, it has so far not been necessary to replace any of the coils on account of defective insulation.

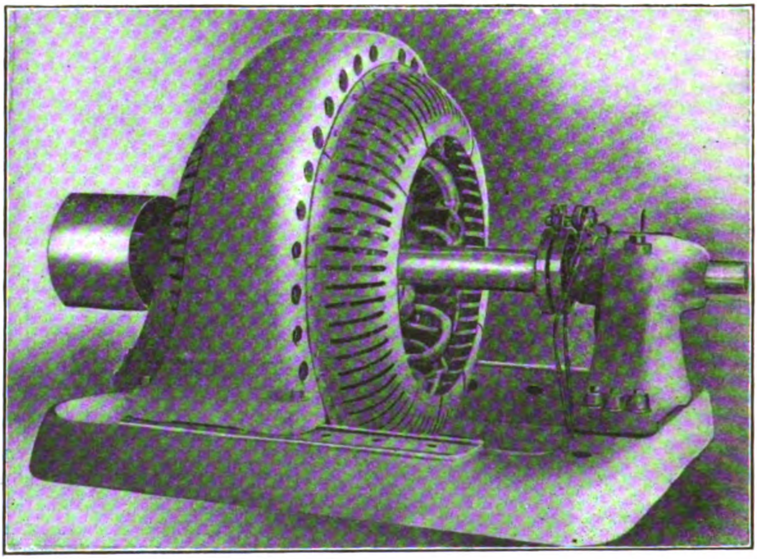

FIG. 4.

SUMMARY

Where individual units of very large capacity are installed in power plants, a potential of 20,000 volts is feasible, and it is to be recommended in units of 10,000 kw. capacity and above.

Where individual units of small capacity are needed for a potential of 20,000 volts, the conditions can be met in most cases, even down to capacities of 150 kw.

DISCUSSION ON "TRANSFORMATION OF ELECTRIC POWER INTO LIGHT," AND "NEW TYPES OF INCANDESCENT LAMPS," NEW YORK, NOVEMBER 23, 1906.

Wm. J. Hammer: If you go back to the first efforts made by inventors in the field of incandescent lighting, you will find that they were mainly devoted to metal filaments, metallic oxides, and rare earths. Subsequently, the pendulum swung in the other direction, and with the development and perfection of the carbon-filament lamp, attention was concentrated upon that. With the exception of a few inventors, work on the metallic filament was at a standstill. Now the pendulum has swung to its original position and we are having this remarkable development in the metal-filament lamp, which bids fair to displace the carbon-filament lamp; but who shall say that perhaps later the pendulum will not again swing in the other direction? Thus does history repeat itself.

About ten years ago two patents were issued on molybdenum, tungsten and other metals in which a heated " fillet " of platinum or carbon was placed in a receptacle and oxychlorides in the form of heavy gases were allowed to descend from the top of the containing globe while hydrogen gas, which is very light, was allowed to ascend depositing the metal in a pure state upon the " fillet " or core. A number of lamps were made, some of which are said to have lasted several hundred hours. No commercial incandescent lamp was made in this way, for the reason that the experimenter did not have the proper " fillet " of platinum, or carbon on which to deposit the pure metal. It was impossible to obtain a " fillet " of sufficiently attenuated character to give a commercial lamp, and in the second place, while some of the lamps lasted several hundred hours they soon became black and could not be used as illuminating agents.

Mr. Howell regrets that nothing had been done on this side of the water in connection with this new development, and I wish to take issue with him. The foreigners have certainly been doing some very excellent work, but we have with us to-night an American inventor whose work dates back to the time when he was a pupil in Philadelphia, and he has ever since been working on rare metals and metallic filaments.

Reference has been made to the work of Professors Waidner and Burgess of the Bureau of Standards which appears in the *Electrical World* of November 10, and Dr. Steinmetz speaks of the practicability of limiting the temperature of filaments to about 1800°, on account of disintegration; but it is interesting to call attention to the fact that the Heany tungsten which was prepared for the Bureau of Standards in Washington, according to the statements in the report referred to, showed the highest melting point of anything tested. The temperature was 3200° cent., and this was without any appreciable discoloration of the glass globe.

Other inventors using the carbon filament (practically the " fillet " already cited) heated it in the presence of oxyhalogen compounds, and also in the presence of hydrogen gas, and asserted that pure metallic tungsten was deposited upon the filament. Those who have had experience with tungsten know that it has a great affinity for carbon, and when once united with carbon forms a carbide, and the melting point drops below that of the tungsten itself, which is a great disadvantage. As Dr. Sharp says in his paper, that method seems to be a practical development of the method shown in patents about ten years ago.

APPENDIX

POWER-HOUSE OUTPUT AND LOAD-FACTOR

The report of the Interstate Commerce Commission gives the total revenue traffic for the entire United States for the year ending June 30, 1905, as 1,038,441, 430 train-miles, of which 459,827,029 is passenger-train mileage, 546,424,405 freight-train mileage, and the unclassified balance, 32,189,996, we have assumed to be mail- and express-train mileage. Including the mail and express trains with the passenger-train service, there is an average of 6.2 passenger and 6.9 freight trains per mile of line per day, or approximately 7 trains each way per day.

Using average weights of equipments, as stated in our paper, and average hauls of goods and passengers, and making allowances for switching, etc., the traffic amounts to 3,000,000 ton-miles per mile of line per annum, of which 600,000 ton-miles are in passenger service and 2,400,000 ton-miles in freight service. In electric operation these figures will be reduced by the weight of engine tenders and a part of the weights on pony trucks.

To supply electric power for the operation of the steam roads, we have assumed that power houses would be located at average intervals of 300 miles. This requires a transmission of 150 miles and for this purpose we have employed in our calculations 60,000 volts. As stated in our paper, both the distance of transmission and the voltage employed are within current practice in plants now in commercial operation in this country, under conditions and for purposes identical with those contemplated in our paper.

In our calculations we have assumed that passenger trains are geared for a maximum speed of 50 miles per hour and freight trains 25 miles per hour, on a tangent and level track. We have assumed that the average run of passenger trains is 10 miles and freight trains 15 miles between stops. With the gear ratios used this gives an average speed of 40.5 and 23 miles per hour, respectively. At these speeds the average load on each power station supplying 300 miles of line is 1.98 passenger trains and 3.84 freight trains, an average of 5.82 trains of both kinds. With equal intervals between passenger and freight trains, respectively, the average load on the power house is 2100 kw., the load-factor is 0.97 and the maximum momentary peak is estimated to be 3000 kw. This method of operation is shown in Fig. 9.

The schedule speeds above mentioned include momentary stops only. As trains are now operated, the average passenger train, owing to stops and delays of various kinds, does not average more than 30 miles an hour, and through and local freight trains probably do not average more than 12 miles an hour. In Fig. 10 we have illustrated the result at the power house if trains are operated at these modified average speeds. The average load remains practically the same as before, while the load-factor is reduced to 0.82 and the estimated maximum momentary peak is increased to 4700 kw.

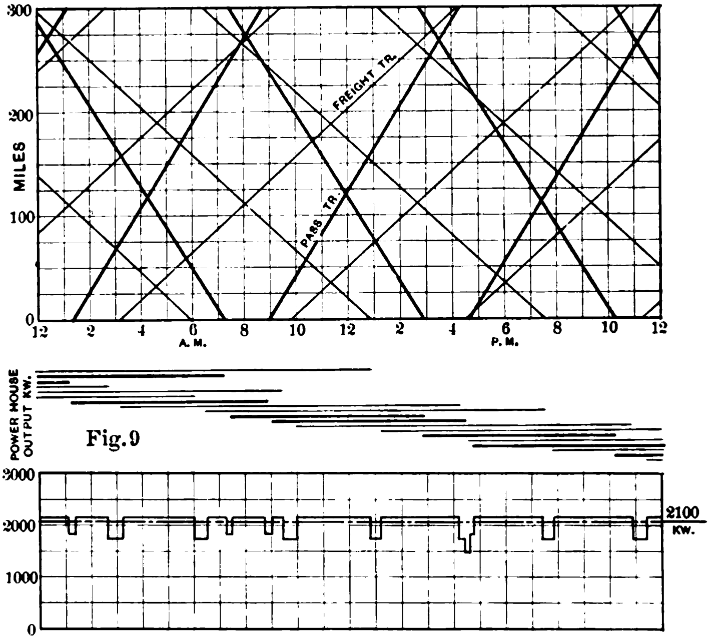

FIG. 9.—POWER-HOUSE LOAD, MAXIMUM AVERAGE SPEEDS.
Passenger trains, 226 tons, 40·5 miles per hr. 273 kw.
Freight trains, 937 tons, 23.0 miles per hr. 351 kw.
Transmission efficiency 90%. Average trains on section, 5.8.
Average power house load 2100 kw. Load-factor 0.968.
Estimated momentary peak 2970 kw., 85% efficiency.

Our estimate of the total power-house capacity for all the railroads of the United States is 2,100,000 kw., which is approximately 3,000 kw. for each 300-mile section. This is nearly 50% in excess of the average load. The generators proposed for this power-house equipment have a momentary overload output of

100% and can carry an overload of 50% for several hours. It is evident, therefore, that the average power plant provided, after deducting 20% for reserve, is ample to take care of ordinary variations in traffic.

It is manifestly impossible for railroads to operate their passenger and freight trains on equal headway. Some roads as a matter of convenience despatch freight trains in " fleets ", and cattle and some produce trains must arrive at their destinations at fixed times of the day. This method of operation is desirable and practicable in steam operation and obviously is objectionable in electric operation, as power-house capacity must be provided for the maximum number of trains on the division. On the other hand, on those roads where traffic is most congested, the track facilities can best be utilized by equal spacing of trains. When this question becomes important, therefore, the natural tendency

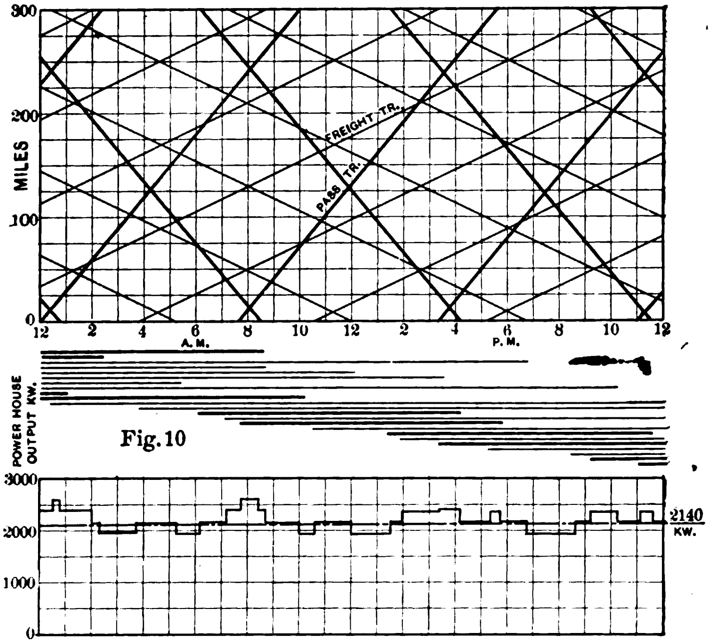

Fig. 10

FIG. 10.—POWER-HOUSE LOAD, MINIMUM AVERAGE SPEEDS.
Passenger trains, 226 tons, 30 miles per hr. 210 kw.
Freight trains, 937 tons, 12 miles per hr. 187 kw.
Transmission efficiency, 90 %. Average trains on section 10.0.
Average power-house load 2140 kw. Load-factor 0.823.
Estimated momentary peak 4720 kw. 85% efficiency.

is towards an approximately equal distribution. As the generators include in our estimates have a continuous overload capacity of 25%, 50% for several hours, and 100% momentarily, and as we have provided an excess of nearly 50% over average demands, the power-house capacity provided appears ample for any reasonable variation in the method of operating trains. In this connection, we wish to call attention to the fact that under average conditions freight trains require 25 hours to traverse the length of line supplied from a single power house; hence if trains are despatched in " fleets " a second fleet will begin to draw upon the power house as the first fleet passes off the power-house load remaining practically constant.

RESISTANCE DUE TO GRADES

In many cases we have found so far as power house-requirements are concerned that the additional resistance, due to grades and curves, can be practically neglected in the electric operation of trains. Unlike the steam locomotive, the electric motor, under certain conditions, operates at higher efficiency on grades and curves than when running free on a straight and level track. This is due to the fact that the motor and gear ratio are properly selected to obtain the highest average efficiency in operation. The effect of this selection throws the load in continuous operation on level track below the point of maximum efficiency. In ascending a grade the speed is reduced, and within reasonable limits this reduction implies an increase in motor efficiency. Again, the reduction in speed, due to grade, results in a reduction in rolling friction and train resistance. These gains are not offset in descending grades unless, in addition to gravity, power be used to attain a speed exceeding the maximum limit which we have assumed, namely, 50 miles an hour in passenger service and 25 miles an hour in freight service. Theoretically, as long as the grade does not introduce a resistance in excess of that of the train-friction independent of the grade, the energy expended in lifting the train will be recovered in overcoming train-friction in going down grade. If the ascending and descending speeds are equal the energy consumption will be the same per ton-mile as on a straight and level track of the same length. If the ascending speed is reduced, as it is in the case of the series motor, the total watt-hour consumption will also be reduced. In Fig. 11 and Fig. 12 we have plotted the effect of grades upon power consumption in both passenger and freight service. In order to keep this discussion distinct from the question of motor and transmission efficiencies, we have assumed a motor efficiency of 85% in all cases and 90% transmission efficiency. All power calculations are carried back to the power house, and that portion of the recuperated energy which cannot be utilized by the train auxiliaries has been returned to the power house at 90% efficiency. Extra electric locomotives are added as needed. With the train weights employed, it will be noted from an inspection of these curves that the power consumption over grades is less than it is over straight and level track in passenger service for all grades less than 0.55%, and in freight service less than 0.35%. Comparatively few lines are absolutely level, but on the other hand the aggregate mileage on grades exceeding 0.5% is relatively small. It is believed, therefore, that the general result as to power consumption will be very close to that required over straight and level track. Nevertheless, as stated in our

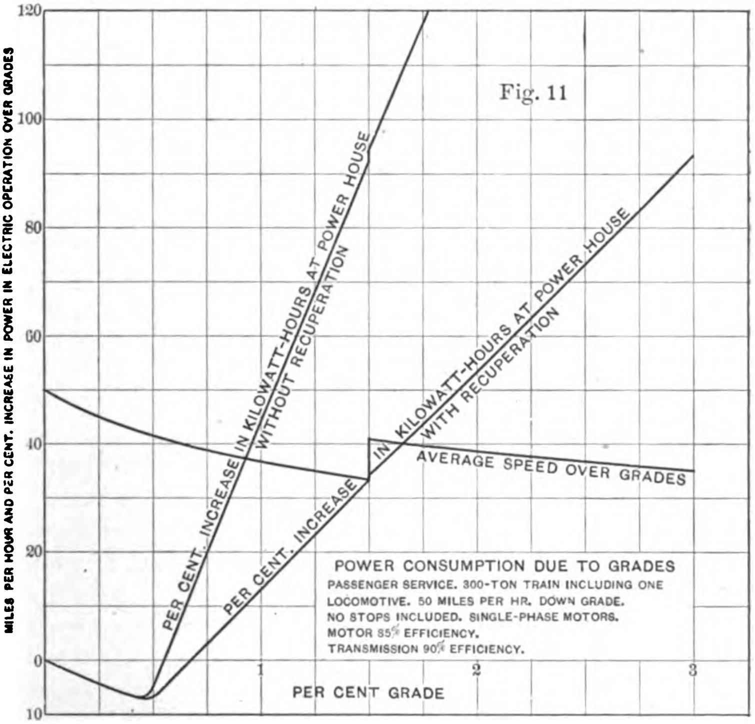

FIG. 11.

paper, we have added to our calculations of energy required 10% in the case of passenger service, and 15% in case of freight service, to cover contingencies, including switching, " double headers " and the additional resistance due to grades and curves.

In some recent calculations in which we went into the subject

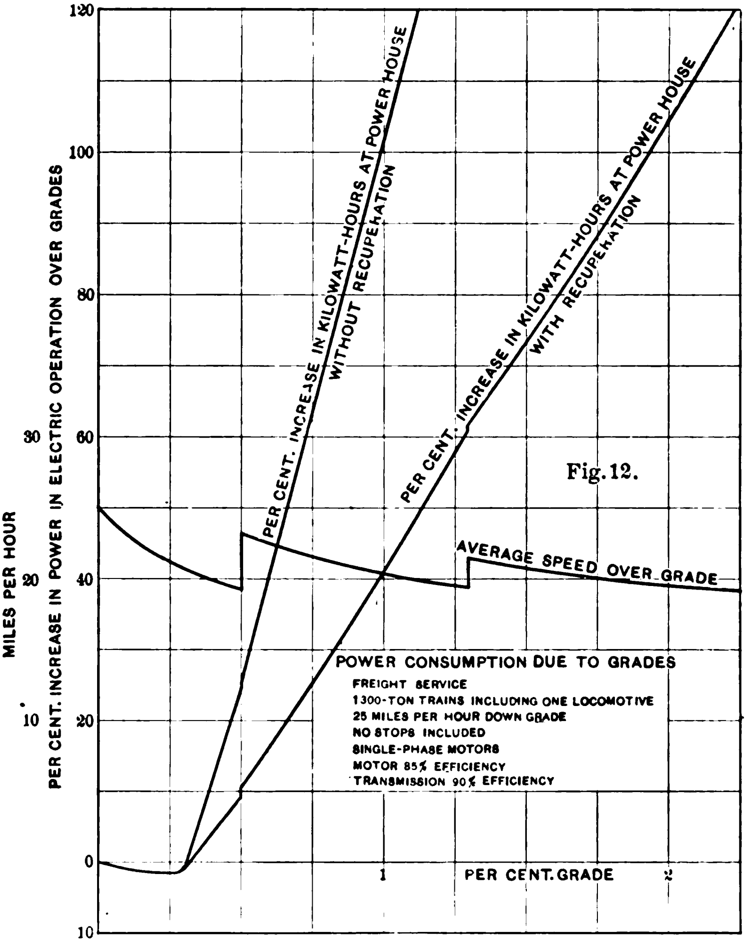

Fig. 12.

in great detail the foregoing conclusions were corroborated. In one case in express service the detailed calculations of runs over the road showed a consumption of power of 53 watt-hours per ton-mile, while 52.8 watt-hours per ton-mile was obtained by using an average run on a straight and level track. In the local service over the same line the figures were 84.2 watt-hours in the detailed calculations and 86 watt-hours for an average run on a straight and level track. These results were obtained from calculations relative to the electrification of the suburban portion of a steam railroad over 30 miles in length; a large percentage of its tracks being on grades and curves. There were maximum grades of 1.47%, 1.55%, and 2.32% and curves of 6° 22′ and 8° 30′. Numerous other calculations and road tests have verified these results.

RECUPERATION.

In making our calculations as to power consumption, we have made no deduction for the electrical return of power to the line. In the case of the higher grades this becomes a matter of importance, as shown by Fig. 11 and Fig. 12. Where the force of gravity due to grade exceeds the amount that can be utilized mechanically in overcoming train-friction, recuperation reduces the increase in power consumption due to the grade by approximately 60% over a grade of 1.5%, so that even in freight service over mountain grades the power required will not exceed that consumed on a level track by more than from 40% to 60%. With recuperation, the power consumption or what is its equivalent, the coal consumption, is not doubled until we reach grades of over 3% in passenger service and 2% in freight service. These grades are considerably in excess of any used on our trunk-line railroads. The ability to recuperate energy is important on lines that have heavy grades. In addition to the saving in power, the saving in wear and tear from mechanical breaking is of as great, and perhaps even greater, importance. The energy represented by the difference between the curves shown on Fig. 11 and Fig. 12 representing the power required at the power house with and without recuperation, increased by the energy losses absorbed by the motor and transmission lines, must be absorbed by the brake-shoes and wheels when mechanical braking is used.

DISCUSSION ON "ON THE SUBSTITUTION OF THE ELECTRIC MOTOR FOR THE STEAM LOCOMOTIVE," AT NEW YORK, JANUARY 25, 1907.

(*Subject to final revision for the Transactions.*)

Frank J. Sprague: This paper has evidently been prepared with a good deal of care, but in certain essentials I am absolutely at variance with some of the conclusions which have been expressed. There is so much to be said, and the time is so limited, that it would be discourteous to the authors and an injustice to myself to attempt to enter into detailed comment, so I shall content myself for the present with only a few remarks.

Briefly, the authors have given an interesting resume of statistical information based almost entirely upon direct-current operation in this country, with some report of results from operation on the three-phase system abroad under conditions differing largely from those characterizing American railroads. They have generalized the features of operation of the steam railroads of the United States, and on that generalization have formulated certain conclusions favorable to the adoption of electricity. All these should receive careful attention and analysis. In addition, they plead for standardization of electric apparatus and equipment, and, if I understand correctly, for a standard of operation based upon the use of single-phase alternating-current motors operated at 11,000 volts and 15 cycles from an overhead trolley.

Their attitude, as expressed in their paper, is emphasized by these two statements:

> The distributing system for altenating-current equipment, which is the only class of equipment deserving serious consideration in connection with the general problem which we are discussing, comprises an addition to permanent way equipment in the form of overhead construction, and electric conductors conveying power from the power house to the trolley or conductor which is carried above the track.
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> The advantage in favor of electric operation is of course more marked if we assume that alternating-current equipment is to be used, as in general would be the case in the electrification of trunk lines or long divisions.

These are certainly positive affirmations, and if sound would perhaps warrant that spirit of enthusiastic and inquiring prophecy in which the sound basic principles which have made electric traction successful are coupled with various unscientific and quickly discarded proposals, and lightly brushed aside with the query:

> Where, ten years from to-day, will be the 1200-volt or 1500-volt direct-current systems which have been suggested as substitutes for high-potential altenating-current systems in heavy electric traction?

I think I see my initials under these specific voltages; and it is right here that I beg to differ from the conclusions expressed by the authors, and venture to correct them. The higher-potential direct-current systems will still be here, just as we have the lower voltages of the past 19 years, no matter what other developments may take place.

I have been guilty, gentlemen, of some "fads and fancies" while a member of this Institute for a time covering the entire practical development of the electric railway, in which I have played some material part; they have been translated into facts. I have ventured a few prophecies; they are now a part of history.

Operation at 1200 to 1500 volts by direct current has not been advanced by me as a "substitute" for high-pressure alternating currents for heavy electric traction, or as the only means available for this purpose; it has been advocated as one practical development along existing lines which under many conditions, and with the present development of the 25-cycle alternating-current motor, offered some possibilities of railroad operation denied to the latter.

I prefer to define my own position rather than to have it determined for me by others. I do not profess to know what the ultimate developments in this art are going to be, nor will I enter into any rivalry in predicting that a specific type of equipment must be universally adopted, for I feel sure that the selection of a system by any road must be largely individual, and determined by its own necessities.

There will be opportunities for alternating-current equipment, and there are many hopeful alternating-current possibilities, but surely these are not the only practicable methods worthy of serious consideration by such trunk-line divisions as may reasonably consider the possibilities of electric operation to-day.

As useful as a mass of statistics may be, I do not think it necessary, to come to specific conclusions in the matter of electric railway equipment, to generalize all the railroads of the United States. There are a lot of them in the hands of receivers, and some of the others ought to be. They could not be taken out of their hands if they were electrified, and could not raise the money to be electrified if they wanted to. I prefer to deal with the living, immediate questions. There will in the near future be three great trunk-line railroads terminating in New York City, to say nothing of those terminating in Jersey City and elsewhere, on which the question of electric operation is assuming special importance. One of them is proceeding along certain lines, another by somewhat different methods. There has been considerable discussion as to the wisdom of both. I have been guilty of some of the development on one, and I am not ashamed of it. I have somewhat frankly criticized some matters connected with the other, and I have no apologies to offer on that account. But leaving these two roads out of consideration, do we need to look further for a typical trunk-line division than to the third road, the Pennsylvania, from here to Philadelphia? An engine run, and none more typical. I am going to venture, not a prophecy, but a statement. If that line were called upon to be electrified to-day—and it can very properly and seriously consider it—it would not, in my present judgment, be best done by a single-phase overhead trolley alternating-current equipment, whether 25 cycles, 15 cycles, or 1 cycle. There would be a variable half cycle, and it would be the length of time between controller operations. And on many other lines which can properly consider electrification, the higher voltage direct-current system, according to any present development, will give better results than the alternating-current overhead system.

These conclusions are based in part upon a four months' study and analysis of one of the most difficult railroad problems in this country. Had I not been closely occupied in trying to complete that particular investigation, I should be in a better position more fully to discuss the paper of the evening. I hope, however, in the comparatively near future to present to this Institute, of which I have had the honor to be a President, a few comparative statements on the subject of direct-current and alternating-current operation, and I will reserve until that time most of what I have to say.

B. G. Lamme: As the time is limited, I shall confine myself to the question of frequency alone. It may be of interest to consider the changes in frequency from the earliest time to the present, and see what Mr. Stillwell has had to do with such changes. Back in the early times of alternating-current, work, 133 cycles per second was the common frequency. About 1889 or 1890, Mr. Stillwell, in going over the problem, saw that the larger work which was coming called for a lower frequency, and he was one of the strongest advocates in adopting 60 cycles as against 133. A few years later, in connection with the Niagara Falls first large generating station, the question of a still lower frequency came in, and Mr. Stillwell practically made the decision in favor of 25 cycles. At that time it was considered that the development of street railway work, and the use of synchronous converters in such work, was such that it was more economical to use the lower frequency. He now comes forward with 15 cycles for heavy railway work on the basis that the field is going to be large enough to call for a new and more suitable frequency.

It seems to me also, considering the total amount involved in the electrification of the railroads of this country, about $1,500,000,000, that the problem is big enough to call for a frequency which is best suited for the work. The question is whether that should be 25 cycles or something lower. Over four years ago I presented a paper before this Institute, in which I described the Washington, Baltimore and Annapolis single-phase railway, and the frequency given was 16⅔ cycles, a ratio of 2 to 3 to the standard frequency of 25. There were certain reasons for adopting that particular frequency, although 10 per cent. higher or lower would not have been of very great importance as far as the operation of the apparatus was concerned. It was found at the time that there was considerable opposition to the use of lower frequency, principally because most of the projects presented involved existing power plants, or it was necessary to tie the new plant to existing power plants. The projects were also relatively small. Because of commerical conditions, we were practically forced to begin at 25 cycles. However, I still advocated the use of lower frequency when it came to heavier work, as will be found in my discussion of single-phase railway apparatus at the Institute meeting at St. Louis Exposition in September 1904. At that time I said that I considered the heavy railway electrification of sufficient importance to warrant the use of a low frequency which is most suitable for such work, independently of any frequencies already in use. I still hold to that opinion.

The strongest reason which can be given for the lower frequency is the greater output that can be got from a given motor. For instance, with a first-class motor, built for 25 cycles, the operation may be above question, the machine may be considered perfect in every way; but take that same machine and operate it on 15 cycles, and the induction can be raised from 25 to 40 per cent., which means that 25 to 40 per cent. higher voltage can be applied with the same motor-speed, and 25 to 40 per cent. greater output is obtained from the same motor, or 25 to 40 per cent. greater tractive effort can be developed. That in itself is a controlling feature in the question. We have verified it by actual test. For instance, we have taken a 100-h.p., 25-cycle motor, and obtained from it 125 h.p. at 15 cycles. This motor has good efficiency, good power-factor, and good commutation on both frequencies, at the above ratings. It is therefore not a question whether the 25-cycle motor will work, for it will work successfully, but it is a question how much more can be got out of it by going to the lower frequency. It may be questioned that if 15 cycles is better than 25 cycles, why is not a still lower frequency recommended? The answer is that at 15 cycles the machine is practically saturated, which fixes the output. At still lower frequency there would be a gain in efficiency and power-factor, but not much in output; and there would be loss in other things, such as the speed of turbo-generators and weight of transformers. So there is some point at which a compromise can be made; and it is my opinion, and has been for a long time, that this compromise is considerably below 25 cycles and should be about 15 cycles.

The increased output to be got from a motor at the lower frequency is of advantage principally in getting a smaller number of motors under a locomotive or car, which directly decreases the cost: or, on a locomotive, keeping the same number of motors, there is obtained a bigger output for a given weight of locomotive. But there are some cases where not much is gained by the use of lower frequency; for instance, where it is necessary to operate alternating current-direct current requiring four motors in order to obtain series-parallel control. In most cases we do not get the full gain from the use of 15 cycles for we can not reduce the number of motors. That is one of the conditions met in the New Haven railway equipment, for the direct-current operation on the New York end requires the use of four motors. There are many cases where the power is purchased in which it is necessary to use the higher frequency. Of course, the results are obtained at a somewhat lesser capacity or at increased cost.

There is one point Mr. Stillwell has not touched on, and that is the fact that the single-phase series motor can be made to operate on both 15 and 25 cycles; for instance, a 25-cycle motor will operate beautifully at 15 cycles and at practically the same speed, because the speed has nothing to do with the frequency. A 15-cycle motor, if well designed, will operate on 25 cycles fairly well, at its nominal capacity; at a slightly reduced capacity it will operate very well, so that if a locomotive should be equipped with transformers suitable for operating at 15 cycles, for instance, it could operate on both 25 or 15 cycles. By taking a 25-cycle equipment, nominally designed for 25 cycles, and putting a 15-cycle transformer on it, the equipment is adapted for operation on both 25 and 15 cycles. That is important in connection with the fact that 25 cycles will have to be used in a certain number of cases, but in other cases where the generating conditions can be made suitable, 15 cycles will work to better advantage.

Mr. Stillwell speaks of some of the advantages of the higher frequency, one of which is the better ratio of tractive effort to weight on drivers. We have been making tests at East Pittsburg on some electrical locomotives, at both 15 and 25 cycles, and it is very difficult to determine any difference in the ratio of tractive effort to the weight on the drivers. In some cases the tests are possibly in favor of 15 cycles, in others in favor of 25 cycles; and the difference is probably no more than would be found in making two consecutive tests at any one frequency. If the motors are spring-connected, or have some flexibility between the armature and the driver, which is true in most cases, especially where they are geared, the difference in the tendency to slip practically disappears.

In discussing this question of 15 cycles, we are asked—where is it in use? I will call attention to the fact that quite a number of European companies have adopted 15 cycles for railway work. The Valtellina, plant put in by the Ganz Company, with three-phase motors, uses 15 cycles; and I feel safe in saying that a great deal of the success and good operation of that plant is due to the choice of this frequency. I think they could have made the apparatus a success with 25 cycles, but it would have required much heavier equipment, and with poorer efficiency and power-factor, especially at low speeds. The manufacturers recognized that 15 cycles gave better conditions with the polyphase motors, and adopted it regardless of the fact that that was not a standard frequency in Europe. That system is being extended on the Italian roads.

The Oerlikon Company of Switzerland, has gone into the single-phase work extensively, with 15 cycles as a standard. The Siemens-Schuckert Company, of Germany, is also manufacturing series railway motors for 15 cycles. The Allgemeine Company, of Berlin, is the principal company which is adhering to 25 cycles, and that is largely due to their type of motor. They have a so-called " series repulsion " motor, in which the characteristics of the motor apparently show to better advantage if the frequency is not too low. It is not directly due to the high frequency that they get better results, but to the fact that the motor should preferably run below the nominal synchronous speed, and this condition is obtained to better advantage by keeping up the frequency.

Bion J. Arnold: On the morning of December 18, 1903, when I arrived in New York from Pittsburg, where I had been examining Mr. Lamme's new single-phase motor and complimenting him on its work, I received a telegram saying that the single-phase locomotive which I had been developing for three years past, and which was at that time ready to make its trial run, had been destroyed by fire. While experimental runs had been made some months before with a rather crude machine, I had everything arranged to make the trial run on the first day of January, 1904, with a new electropneumatic motor which I had developed, and by means of which I expected to demonstrate a single-phase railway in operation. I did not then discover, nor have I yet discovered, the cause of the fire, but it burned up the machine. I felt that unless the machine were rebuilt and an attempt made to operate it, I might be misunderstood by those not familiar with the circumstances. I therefore rebuilt the machine and operated it on August 3, 1904, in time to antedate my competitor in this country by some days. That experiment cost me about $50,000, but thanks to good fortune it cost no other man a dollar.

I believe that by this experiment I was instrumental in advancing the state of the art to such an extent that to-day two or three of our large railroads are being equipped with the single-phase system, invented by others, to be sure, but I believe forwarded by my efforts of some four or five years ago. If my efforts have done that, and I have been instrumental in advancing the art, I am glad I spent the money, as I could not have spent it in any better cause.

I shall not attempt to go into a detailed analysis of the various systems which are involved in the paper, because I think each system has its able champions. It makes no great difference to me personally which system wins, so long as we get a system of electric railroading in this country that will operate the trains for less than it now costs to operate them by steam. I had that idea in mind in starting out on the single-phase experiment, because in 1898 I was engaged in building the Chicago and Milwaukee electric railway, which I believe is considered the pioneer synchronous converter sub-station railroad in the country, possibly in the world; at any rate, the first to be driven by a steam station. I took much risk in that undertaking, risking my personal reputation and my financial resources, in order to demonstrate the success of that enterprise. It was a success, and as you know most of the suburban roads have since been built on those lines.

I make no claim for the invention of many of the devices which entered into the systems. They were invented by some of the gentlemen here present, and by others, and some had just begun to come into commercial use; namely the synchronous converter, which made the system possible; but I took the risk of putting into practice such a system, took the engineering and financial responsibilities, of making it go It went. When engaged in that work I felt that that system was not the complete solution of the electric railway problem, because the introduction of the synchronous converter substation necessitated men in the sub-stations, and necessitated more investment than I thought the railroad systems of the country could stand if they were to be attracted to electrical operation. That started me on the single-phase idea, and as many of you will recollect, we had various discussions on the subject, and it was stated by some of those here present who are now advocating the system, that it could not be done. I maintained it could be done, and had to be done, and it cost me much to find that out. It has been done since by at least two companies in this country, and two or three abroad and seems to be coming quite rapidly into practice for steam railroad work.

I do not agree entirely with the authors in regard to standardizing this apparatus, as this would shut out the utilization of the talent of the members of this Institute and other societies in this country, and other countries, and the prospect of developing something that may prove better than anything we have now. I am willing to concede, if we are going to use alternating-current railway systems, that we should adopt a standard frequency. So far as my investigation has gone, in conjunction with Mr. Stillwell as a member of the electric traction commission of the Erie railroad, my leaning is toward the 15-cycle frequency. Although I do not want definitely to stand on that conclusion now, I think it is the frequency we will come to on account of the fact that to get the requisite amount of capacity between the wheels of a railroad-car truck, the gauge being limited, it is necessary to get as much power in the space as possible. This can be done by adopting 15-cycle motors, as these motors are more powerful than 25-cycle motors of equal size. It makes the total weight of the locomotive or car practically the same as at 25 cycles, as it increases the size of the transformer. Even then we do not get as much power on the wheels with the alternating-current motor as with the direct-current motor.

I personally believe that some form of high-potential overhead conductor is going to be the final solution of the railroad electrification problem. I believe in the third-rail, where it is applicable, but I do not believe there are many places where it is applicable; in other words, I think that legislation in this country will prohibit the use of the third-rail in exposed places. There are certain types of third-rail which have recently been adopted, which I believe are safer than previous third-rails; I refer to the rail that was devised by Messrs. Wilgus and Sprague and used in the New York Central installation—but I do not think that the use of the third-rail in yards, and under the feet of men, and in other exposed places, will be accepted as the final solution of the problem. In the analysis of the Grand Trunk problem, which I have in charge so far as the engineering decisions are concerned, I chose the alternating-current system, overhead conductor, for tunnel work principally, for the reason that in the large yards at each end of the tunnel, where much switching is done, it seemed essential that the conductor be kept from under the feet of the men. The decision to use the single-phase motor was made some five months prior to the decision by the officials of the New Haven Company to adopt the alternating-current system on their road. The officials of the Grand Trunk did not publish their decision, as certain matters had to go abroad for approval by the English officials before the matter could be publicly announced, but there are men in this room who know that the decision was made at that time.

W. B. Potter: I heartily endorse the recommendation of the authors of this paper as to the desirability of making an effort toward standardizing the essential principles which are involved in the determination of electric railroad problems. To this general proposition may well be added the plea for a uniformity of dimension for such parts of the equipment or general system as might reasonably be made interchangeable.

Considering the matter of standardization in its broader aspect, there does not appear to be any one general system of electrification, in the present state of the art, which engineers would be willing or ought to accept as the standard. For the ordinary city or interurban trolley lines, 600 volts direct current is to-day recognized as a standard. For other classes of work, particularly over long-distance lines with relatively infrequent headway, both the single-phase alternating and the high-voltage direct-current systems possess advantages. The fundamental reasons, however, which have lead to the consideration of a higher voltage trolley may also apply to limit the application of the high-voltage trolley under conditions which can be more economically met by 600-volt apparatus. However much we may desire to limit the number of standard systems we must still recognize that the element of cost, considered broadly, is often the determining factor to be reckoned with. A railroad company could hardly be expected to consider favorably any particular system simply because of general reasons, if the installation of this system involved any considerable additional expenditure on their part.

The matter under discussion this evening, however, relates more particularly to the consideration of the single-phase alternating system than a discussion of the general subject. Of all the apparatus used in the electrification of a railroad, the motor is in particular that part of the equipment which is limited in dimension by the height of the car-body, the clearance over the rails, the width between wheels, and the wheel-base of the trucks. By reason of these limitations, and considering further the proportion of cost which the motors bear to the general expense of electrification, any condition which diminishes the capacity of a motor of given size may very well become subordinate to the motors themselves.

The output of a single-phase motor, particularly its tractive power in the larger sizes, may be limited by the permissible commutation, and as commutation is improved with reduced frequency the suggestion of 15 cycles instead of 25 cycles is worthy of serious consideration. The field of application for the single-phase motor, particularly in the larger sizes which are required for locomotives and heavy railroad operation, will unquestionably be greater if the motors are operated at a lower frequency than 25 cycles.

Compared with a direct-current motor, a 25-cycle motor of corresponding service capacity would weigh approximately 25% more; while at 15 cycles, the single-phase motor would weigh probably not more than 10% in excess of the direct-current motor. The efficiency and power-factor of the single-phase motor on either 25 or 15 cycles would be approximately the same. While the motors and the reactance of line and track are benefited by a lower frequency, there is the increased cost of the generators and transformers to be taken into account.

Messrs. Stillwell and Lamme have both spoken of the effect of a lower frequency upon the maximum available tractive effort. You will appreciate that owing to the characteristics of an alternating current, the average tractive effort of the single-phase motor is approximately 50% of the maximum at the top of the current wave, and with a motor rigidly mounted the wheels would begin to slip at about one half the tractive effort which would be given by a direct-current motor under the same conditions of track and weight on drivers. With the motor mounted on springs in the usual manner, there is introduced some degree of flexibility, and the impulse due to the top of the wave is absorbed by the springs so that the average torque is considerably higher than the theoretical 50%. Under similar conditions of track, with equal weight on drivers and the same method of mounting, tests have been made which indicate that in comparison with the same motor on direct current, the maximum available tractive effort at 25 cycles is from 80% to 90%, and on 15 cycles from 70% to 80%. The maximum available tractive effort is not generally important except in locomotive operation where the maximum draw-bar pull is in a sense the measure of the locomotive's value for starting a train, and during acceleration. On motor cars there is usually an excess of weight on the drivers over that required for acceleration, so that the maximum tractive effort is a matter of less importance.

It is, incidentally, an interesting fact that after the wheels have commenced slipping the direct-current motor shows a much greater reduction in tractive effort than the single-phase motor. The torque being maintained uniformly with a direct-current motor, the wheels rotate rapidly, reducing the coefficient of friction with the rail to something like 20% or 30% of the maximum adhesion. With the alternating-current motor, both on 25 and 15 cycles, although the initial slip is at a lower maximum, the draw-bar pull is only reduced to 80% or 90% of the maximum adhesion. This appears to be due to the fluctuating character of the torque, which at its minimum allows the wheel to secure a slight grip on the rail after the wheel begins to slip. When the wheel is slipping its rotation is not uniform but fluctuates, corresponding with the frequency. While of interest, this higher tractive effort, after the wheels commence to slip, is of little practical value.

Mr. Sprague has referred to higher voltage direct-current motors. With respect to motors suitable for operation on higher voltage direct current and also on 600 volts, I would mention the marked improvement in the motor that has been obtained by the addition of a commutating pole. As an illustration, a motor having commutating poles and designed for operation on 600 volts, can be run at full load on 1000 volts so far as commutation is concerned, and further, such a motor, when the current is momentarily interrupted or there is a momentary rise in voltage, will not flash over, as sometimes happens with motors not having commutating poles. A commutating-pole motor designed for 1200 volts and operated at that potential would be superior to the ordinary 600-volt motor, both with respect to commutation and liability to flash over. I feel that the addition of the commutating pole to the direct-current railway motor, in its effect on commutation, is comparable to the improvement made by the substitution of the carbon brush in place of the copper brush. The carbon brush reduced the sparking and flashing to a permissible degree, and the commutating pole by neutralizing the cause has finally eliminated defective commutation.

A word with regard to the much maligned third-rail. I feel that there is much to be said in its favor. We have not as yet had an equal opportunity to pass judgment on the heavy overhead construction, and I would suggest that we await developments before expressing our opinion too positively with regard to either system of conductors. Both the third-rail and the overhead conductor have a proper field in heavy railroad application; they should be so regarded, and neither of them condemned in the light of our present knowledge.

W. S. Murray: During the year and a half that I have been associated with the New Haven road I have been able to make some rather interesting experiments with steam locomotives, of the freight and passenger types. I thought they might be of interest, particularly in view of Mr. Stillwell's reference to Item 12 of the paper, which relates to "Repairs and Renewals of Locomotives." I understand that this item, for the Valtellina line, represents a figure of 1.8 cents per locomotive-mile. That is a figure I have been very anxious, indeed, to obtain. I have here some accurate figures on the cost of steam locomotive repairs extending over a period of exactly one year, in which ten freight and ten passenger engines were involved. I think you will all be surprised to note what these figures are. I have divided the cost of repairs into two parts; one on the basis of maintenance, the other for purely mechanical or shop repairs, each including labor and material. I have included in the maintenance the following heads: Cost of oil and waste, flues cleaned, ash-pan and grates cleaned, engines wiped, engines turned, engines fired, boilers washed, and the cost of sand. Of course, some of these figures will be matched in electric operation, but to get the actual figure I have included them all.

The record is as follows:

For passenger locomotives: maintenance **$0.0172**; shop repairs $0.0388; total repairs per locomotive-mile **$0.056.**

For freight locomotives: maintenance **$0.0142**; shop repairs $0.0668; total repairs per locomotive-mile $0.081. I believe that these figures give a definite idea of the saving to be effected by the electric method of train propulsion.

I think the most interesting feature of the paper is in regard to the matter of standardization. I hardly think the Interstate Commerce Commission reports are a fair basis to be a determining factor in the establishment of a standard frequency. The Interstate Commerce Commission report includes all the transcontinental lines, and there is no doubt that those lines which have been unassailed yet by electricity could be electrified a great deal cheaper with low-frequency than with high-frequency apparatus, but I do not think that this fact should influence us. I think it is a misleading factor. We must not forget that the electrification of steam railways we are going to consider for the present are to be intimately connected with 25-cycle plants now in operation. It is possible that all of us may see a transcontinental road electrified, but I do not think that that ought to influence us in the determination of a standard frequency.

What " may be " should not decide this question but " what is." I think we should remember the fixed charges associated with 25-cycle plants that have not been taken into account in this report, and that the new frequency universally applied would make it necessary to re-equip all these plants operated upon what may now be termed a standard frequency; namely, 25 cycles.

I believe that for power transmission purposes we will all agree that 25 cycles has nearly occupied the position of a standard frequency. Now then, the fixed charges of the properties operated upon a 25-cycle frequency can later be taken care of by a properly provided depreciation figure or sinking-fund, and at the expiration of the depreciation periods we can avail ourselves of the greater data to decide which should be the standard frequency. The gradual interchange of the two frequencies can then be effected without hindrance to operation.

I have not time here to go into the details of this change, but I am sure all of us are agreed that this can be done. I am in favor of having more data and in letting the future consideration of the new data, in connection with the old, decide the proper standard frequency

O. S. Lyford Jr.: This paper is a prophecy. It is interesting to note that the fulfilment of the prophecy has already begun One of the oldest railroads in the country has proved itself the most progressive and has during this present week put into commercial service an electric traction system which embodies most of the features which the authors have assumed as probable characteristics of the standard of the future. Two other roads referred to in the paper have made a start in the direction proposed, but the Erie was the first to arrive. On January 22 the Erie Railroad ran its first electric train into Rochester.

The essential features of the Erie equipment are as follows:

Single-phase railway motors.

Multiple-unit control.

Pantagraph trolley.

Trolley wire supported with steel catenary construction at a height of 22 feet, except under bridges.

Trolley voltage. 11,000.

One sub-station feeding 34 miles of track.

Power received from a power station 90 miles away over a 60,000-volt transmission line.

The conditions are in many ways almost identical with the assumptions made by the authors.

I may say that the operation of the entire equipment was perfect and fully demonstrated the sufficiency and general practicability of the system. On the return trip the Vice-president's private car was hauled as a trailer, resulting in a total weight of train 22 per cent. heavier than that for which the motors were designed. This was on icy, slippery rails.

The impression given by the overhead catenary construction is that it is the adequate thing for heavy railroading. An

11,000-volt trolley wire so supported is a safe proposition. The 11,000-volt wires on the car are so short and so well guarded that they are not a source of increased danger, and all the other wires, housed in the usual way, and operated at only one-half the usual voltage, are unusually safe.

The system in this case is necessarily operated at 25 cycles, as the power comes from one of the Niagara Falls plants, which are all built for 25 cycles. The advantage of the lower frequency is apparent, however, Trucks of unusual size are entirely filled with 100-h.p. motors. At 15 cycles, motors of 150 h.p. capacity could be used on the same trucks.

Referring to that part of the paper which relates to comparative costs of operation, more emphasis should be placed on the tabular matter and the deductions made therefrom. The one question is: can steam railroads be operated more economically by electricity? The three items which I presume will be most questioned are Items 12, " Repairs and Renewals of Locomotives;" Item 21, " Engine and Roundhouse Men;" and Item 22, " Fuel for Locomotives," or, in the case of the electric work, the cost of power delivered to the locomotive. I do not propose to discuss these different items in detail, but I would like to point out the fact that they might even be doubled, and still the electrical operation would not cost more than steam. Those of us who have had occasion to study different specific problems have found that the adoption of electric traction, particularly if a high-voltage trolley is used, will not mean an operating cost greater than the cost of steam, and in many cases the saving is considerable. In other words, specific cases which have been investigated, as well as this study of the problem as a whole, show that electric traction is commercially practicable for such lines as can provide for the initial investment. Furthermore, the advantages to be gained by electric traction, due to increased facility of operation and increased loads which can be carried, have not been capitalized in this paper.

The trunk lines of the country are confronted with the problem of more capacity, as has recently been strongly emphasized by Mr. J. J. Hill. There is no doubt but that more traffic can be handled with electric than with steam locomotives, and, at equal cost per locomotive-mile electric traction can be adopted to great advantage by the railroads of this country. On such an occasion as this we should place emphasis on this one important fact and not get into too much discussion of details.

C. L. de Muralt: Mr. Stillwell and Mr. Putnam have covered the questions of comparative energy consumption and comparative operating costs so ably and so fully that there is not much room left for discussion on these points. But on the subject of comparative speed and power characteristics of the various types of locomotives I believe I am in a position to add a few figures which may be of some interest to you. I have had occasion to make an investigation into the hauling capacities of certain locomotives when operating under heavy load conditions. The diagrams compiled during this investigation showed so strikingly the superiority of the electric locomotives over their steam competitors, and, incidentally, also the great superiority of the three-phase aternating-current locomotives over any other type of electric locomotive, that I thought it worth while to elaborate the results somewhat to present them for your consideration.

To make the comparison as broad as possible I have taken what I thought to be the most representative locomotives of their respective classes: the latest direct-current locomotives of the New York Central and Hudson River Railroad, the single-phase alternating-current locomotive of the New York, New Haven and Hartford Railroad, and a European three-phase alternating-current locomotive of the type used by the Italian State Railways. And with these I have compared a Pacific, an Atlantic, and a Consolidation type steam locomotive of recent American Locomotive Company's design—all the steam locomotives being chosen with reference to possessing the greatest possible power; that is, the greatest feasible heating surface, consistent with their weight on drivers.

Detailed descriptions of the mechanical and electrical features of the New York Central direct-current locomotive have appeared in the technical press[1]. So I will simply repeat here some characteristic figures required for the comparison:

Total weight, 95 tons.
Weight on drivers, 68 tons.
Nominal rated horse power, 2200.
Maximum horse power, 3000.
Maximum tractive effort at starting, 34,000 lb.
Three main running speeds:
  a. Four motors in series.
  b. Two groups in parallel, each of two motors in series.
  c. Four motors in parallel.
Normal operating pressure of motors, 600 volts.

On the New York, New Haven and Hartford single-phase alternating-current locomotive, complete data were published last year[2], and I merely extract the following figures:

Total weight, 85 tons.
Weight on drivers, 85 tons.
Nominal rated horse power, 1000.
Horse power in continuous running, 800.
Maximum tractive effort at starting, 42,500 lb.
Speed controlled by voltage variation, motors permanently connected two in series, two in parallel, numerous speed steps.
Normal operating pressure of motors, 235 volts.

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[1] *Street Railway Journal*, November 19, 1904.

[2] *Street Railway Journal*, April 14, 1906.

The three-phase alternating-current locomotive has four driving axles and three motors suspended between them, and the locomotive possesses the following characteristics:

Total weight, 95 tons.
Weight on drivers, 95 tons.
Nominal rated horse power, 2250.
Maximum horse power, about six times nominal full load rating.
Maximum tractive effort at starting, 47,500 lb.
Three main running speeds:
a. Three motors in cascade connection.
b. Two motors in cascade connection.
c. Two motors in parallel.
Normal operating pressure of motors, 3000 volts.

A locomotive of exactly the same type, but slightly lighter, has the following typical dimensions:

Total weight 85 tons.
Weight on drivers, 85 tons.
Nominal rated horse power, 2000.

I refer to the heavier locomotive as type A, and the lighter one as type B.

Descriptions of the three steam locomotives will be found in the American Locomotive Company's publication. The principal features of the Pacific type locomotive (No. 1212, of the Southern Railway) are as follows:

Total weight including tender,	175	tons.
Total weight of engine alone,	109	"
Weight on drivers,	67	"
Cylinder diameter,	22	inches.
Stroke of piston,	28	"
Diameter of drivers,	72.5	"
Total heating surface,	3895	sq. ft.
Maximum sustained horse power,	1640	
Maximum tractive effort at starting,	33,500	lb.

The Atlantic type of locomotive (No. 3000, of the New York Central and Hudson River Railroad) has the following characteristics:

Total weight including tender,	161	tons.
Total weight engine alone,	100	"
Weight on drivers,	55	"
Cylinder diameters,	15½ and 25	in.
Stroke of piston,	26	"
Diameter of drivers,	79	"
Total heating surface,	3445	sq. ft.
Maximum sustained horse power,	1360	
Maximum tractive effort at starting,	27,500	lb.

And, the Consolidation type locomotive (No. 221, of the Delaware and Hudson Railway) may be briefly described as follows:

Total weight including tender,	164	tons.
Total weight engine alone,	96.5	"
Weight on drivers,	85	"
Cylinder diameter,	21	in.
Stroke of piston,	30	"
Diameter of drivers,	57	"
Total heating surface,	3408	sq. ft.
Maximum sustained horse power,	1020	
Maximum tractive effort at starting,	42 500	lb.

All of these locomotives have a maximum speed of about 70 miles per hour except the Consolidation, the maximum speed of which is about 40 to 45 miles per hour.

The running characteristics, expressed in the shape of tractive effort, speed curves, of all of these locomotives are indicated in Fig. 1.

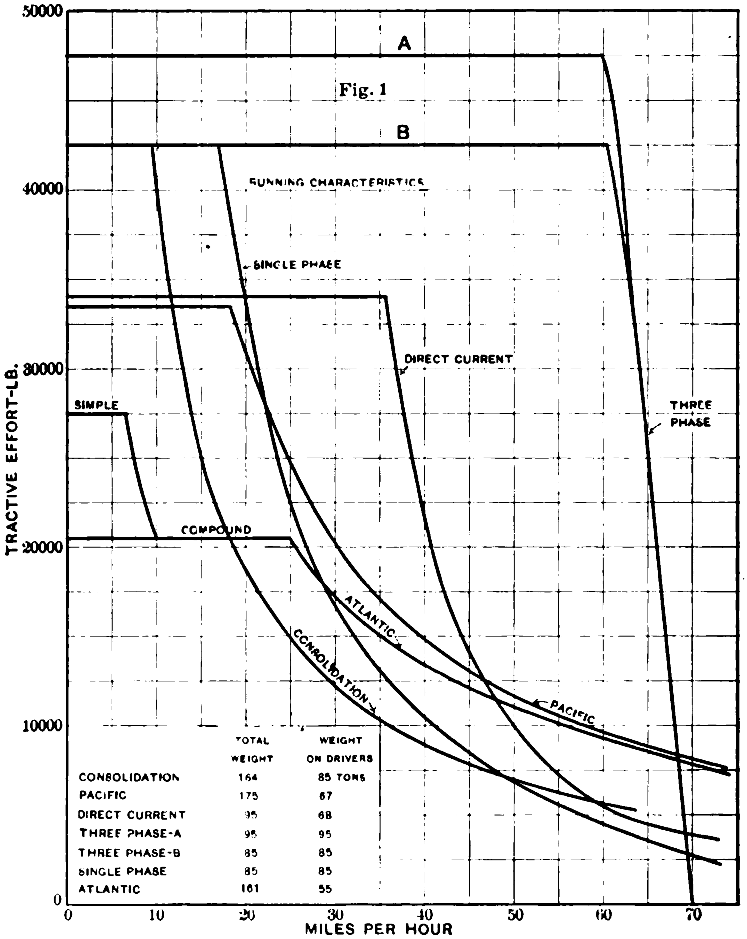
All of these curves start at a point corresponding to the maximum tractive effort which is obtainable by the full use of the adhesive weight of the locomotive, just below the point where the wheels begin to slip. This maximum tractive effort, dependent only on the adhesive weight, can for each locomotive be counted upon up to a certain well determined speed. Beyond that point, clearly shown in the curves, the maximum tractive effort is independent of the adhesive weight and dependent on the maximum power which the locomotive can develop. And it is from this point that the various locomotives show marked differences in behavior.

The horse power which a steam locomotive can develop is determined by the amount of water which the boiler can evaporate and the economy of the cylinders. If W represents the pounds of water evaporated into steam per hour at the given pressure, and N the water rate of the cylinders in pounds of steam per indicated horse power hour, then the maximum indicated or cylinder horse power in this part of the curve is $\frac{W}{N}$. Tests conducted under the auspices of the Pennsylvania Railroad at the Louisiana Purchase Exposition in 1904, showed that the evaporation per square foot of heating surface per hour for different types of locomotives varied between 8 and 16 pounds, also that the steam consumption of the cylinders averages 23.7 to 29 pounds per indicated horse power-hour. The largest Consolidation locomotive built, with 100 tons on drivers, has about 4000 square feet of heating surface; the largest Pacific locomotive, with 67 tons on drivers, about 3900 square feet; and the largest Atlantic, with 57.5 tons on drivers, about 3600 square feet. The average evaporation and the average economy under service, not test, conditions, is approximately 12 pounds per square foot of heating surface per hour, and 27 pounds per indicated horse power-hour, respectively. For one horse power developed in the cylinders there must thus be 2.25 square feet of heating surface in the boiler, or:

Cylinder horse power = 0.43 × heating surface in square feet and:

$$\text{Tractive effort} = \frac{375 \times \text{cylinder horse power}}{\text{speed in miles per hour,}} - \text{frictional tractive effort} =$$

$$\frac{161 \times \text{heating surface in square feet}}{\text{speed in miles per hour}} - \text{frictional tractive effort.}$$



	TOTAL WEIGHT	WEIGHT ON DRIVERS
CONSOLIDATION	164	85 TONS
PACIFIC	175	67
DIRECT CURRENT	95	68
THREE PHASE-A	95	95
THREE PHASE-B	85	85
SINGLE PHASE	85	85
ATLANTIC	161	55

Fig. 1.

The machine efficiency varies in different types, over the range of speeds, from about 74% to 93%. The mean effective pressure corresponding to frictional loss is very nearly constant for all speeds and cut-offs, and averages 3.8 pounds per square inch. The maximum tractive effort, therefore, is given by the relation:

$$\text{Tractive effort} = \frac{161 \times \text{heating surface in sq. ft.}}{\text{speed in miles per hour,}} - \frac{3.8\, d^2 L}{D}$$

where d is diameter of cylinder in inches, L the length of stroke in feet, and D the diameter of driver in feet. This formula, developed by Professor Goss,[1] for simple engines, has been found to corroborate actual tests with exceedingly good accuracy. The majority of the curve sheets in the Pennsylvania tests referred to, show the calculated and test curves in practical coincidence. The curve of the Atlantic type, four-cylinder balanced compound locomotives, No. 3000 of the New York Central and Hudson River Railroad, was plotted from an actual test made at St. Louis.

The curve obtained from the above equation represents the normal continuous output of the steam locomotive. This continuous output is practically the maximum output, since the overload capacity of the steam locomotive is limited to perhaps 25% for periods not exceeding 5 minutes, on account of the impossibility of forcing the boiler above its normal capacity for extended periods.

Electric locomotives, on the contrary, can sustain overloads of considerably greater magnitude for much longer periods of time, without any difficulty.

The curves of the direct-current and the single-phase alternating-current locomotives are very similar in character to the curves of the steam locomotives. These electric locomotives have motors, with so-called series characteristics, that slow down in speed with any increase in load. The direct-current and the single-phase electric locomotives, in common with the steam locomotive, will therefore reduce their speed when they are called upon to haul an increase in load, either in the shape of a heavier train or when running up-grade.

This feature is clearly shown by the curves in Fig. 1, and it is quite interesting to note that the curves of the steam and electric locomotives cross each other. In other words, the tractive effort of the direct-current and single-phase alternating current locomotives, which is better than that of the steam locomotive at low speeds, actually drops off considerably faster with increasing speed, until it is much worse than that of the steam locomotive at high speeds. In fact, if we consider carefully, the curve of the steam locomotive is the result of practically constant power output, while with the direct-current and single-phase alternating-current locomotive the power output as such diminishes together with the tractive effort.

But the greater advantage of the electric locomotive lies in the fact that it can utilize its weight very much better than can the steam locomotive; and if the actual values of tractive effort taken from the curves are compared with the weights of the corresponding locomotives it will be found that the direct-current and the single-phase alternating-current locomotives are capable at low speeds of exerting a very much greater tractive effort proportional to their weight than can the steam locomotives, and even at high speeds their proportional performance is better than that of the steam locomotive.

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[1] New England Railroad Club, December, 1901.

An additional, and perhaps even more important advantage of these electric locomotives over their steam competitors, lies in the fact that the electric locomotive can readily respond to almost any kind of overload demand. As a matter of fact, a prolonged grade for instance, may seriously decrease the usefulness of a given steam locomotive, due to the impossibility of forcing the latter's boiler for any considerable length of time above rated capacity ,while the electric locomotive will slow down, of course, but will, with the assistance of the power house, carry great overloads for any reasonable length of time.

The three-phase alternating-current locomotive not only accomodates itself to such increased demands on its hauling power, but it does so without any great drop in speed, and automatically adjusts its power to the demand. If at 1500 horse power normal output the motors of a given three-phase locomotive have a 2% slip, then at five times the normal tractive effort the slip will be approximately 10%, and the speed will drop from 68.5 to 63.0 miles per hour. Three-phase induction motors of this size (750 horse power) can be built with a maximum torque of 6 to 7 times full load-torque with very good electric qualities. And, notwithstanding the objection sometimes urged that the design must be very liberal for such service, it remains a fact that the three-phase motor can do what the others cannot do, and its intrinsic lighter weight per horse power, its higher efficiency, its more economical distributed winding, and the absence of the commutator, keep down the cost of the three-phase locomotive within the limits governed by competition.

It goes without saying that this constant-speed variable-power characteristic of the three-phase locomotive need not necessarily be made use of in cases where a decrease in speed is no serious objection; while it may perhaps be desired to keep the power within limits. In such cases the three-phase locomotive can just as well be run at lower speeds for the heavier draw-bar pulls. But it may be well to point out here that the power required; for instance, for a 300-ton train running at about 70 miles per hour on a grade of 0.335%, is the same as that required to accelerate the same train on the level with an initial acceleration of 0.56 miles per hour per second. Inasmuch as the system will be designed for the maximum power demands caused by the heaviest trains accelerating, no additional investment in copper or machinery will be required by this constant-speed, variable-power characteristic of the three-phase locomotive.

Instead of saying that the three-phase locomotive is capable of maintaining practically constant speed under any load, while direct-current and single-phase locomotives will drop in speed with increasing load, the thesis may be reversed and the equally true statement be made that the three-phase locomotive is able to develop a certain given tractive effort from zero clear up to practically maximum speed, while the tractive effort of the direct-current and the single-phase locomotives will fall off seriously with increasing speeds, and at maximum speed is only a fraction of what it was at low speed. The curve of the direct-current locomotive shows, for instance, a drop from more than 3000 horse power at 36 miles per hour to only 960 horse power at 60 miles per hour, and the curve of the single-phase locomotive a drop from about 1540 horse power at 23 miles per hour to only 670 horse power at 60 miles per hour. And this is not a question of liberal design, but an inherent unalterable characteristic of all locomotives using series motors.

These features are brought out very clearly by the curves of Fig. 1, but a few hypothetical examples may go to show just exactly how these characteristics affect the actual hauling of trains.

Let us take a locomotive capable of hauling a 150-ton train, and run it over a given stretch in, say 16 minutes, by the use of a maximum running speed of about 65 miles per hour. Now increase the train-weight to 300 tons. The three-phase locomotive will haul the heavier train over the given stretch as before, in 16 minutes, but the direct-current locomotive or the single-phase alternating-current locomotive will have to drop in speed, and will now take 18 minutes to cover the same distance. A loss of over 10% in time, which loss increases with increasing load.

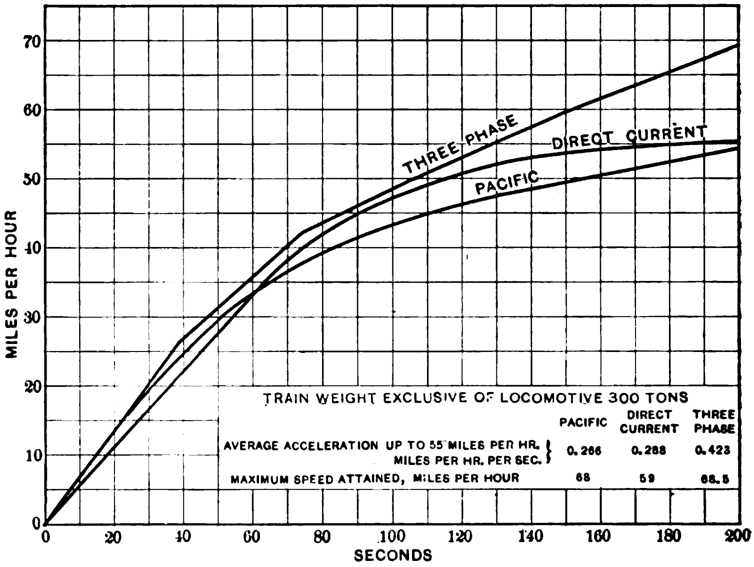
Or take a line of track with one or more grades. Hauling trains of the same weight, the direct-current locomotive and the single-phase locomotive will, compared with the three-phase locomotive, lose a certain amount of time at each grade, and their total running time will, with the same maximum speed, be necessarily considerably poorer than that of the three-phase locomotive.

Or, take the actual curves of Fig. 1 and send the locomotives over a level line at an average running speed of 60 miles per hour, which corresponds to a schedule speed of about 50 miles per hour with stops about 15 miles apart. We then find the maximum tractive effort for each locomotive, and the maximum trailing load which each can haul (assuming a train resistance of 17 pounds per ton) to be as follows:

	Maximum tractive effort	Weight of locomotive and tender	Trailing train weight
Single phase .	4250 pounds	85 tons	165 tons
Direct current	6000 "	95 "	258 "
Atlantic.....	9250 "	161 "	382 "
Pacific.......	9750 "	175 "	398 "
Three-phase	9375 "	95 "	457 "

If we investigate the maximum grade which each locomotive can take with a given train at a given speed we shall find the same order of things. It seems, therefore, entirely fair to draw the broad conclusion that for its weight the three-phase locomotive is by far the most powerful hauling engine extant.

To complete the comparison I have plotted a few curves Figs. 2, 3, and 4) showing the relative accelerations which can be obtained from the various locomotives above referred to, and I have endeavored to bring together for this purpose locomotives directly comparable, as much as possible, with reference to their weight characteristics. In Fig. 2, I compare the Pacific type steam locomotive (109 tons, 67 tons on drivers) with the direct-current locomotive (95 tons, 68 tons on drivers) and the heavier of the two three-phase locomotives (95 tons, all on drivers). On Fig. 3 the Atlantic type (100 tons, 55 tons on drivers), a most powerful engine for its weight, is compared with the single-phase locomotive (85 tons, all on drivers) and the lighter three-phase locomotive (85 tons, all on drivers). And on Fig. 4 the Consolidation (96.5 tons, 85 tons on drivers) is compared with the lighter three-phase locomotive (85 tons, all on drivers). These weights are sufficiently close together to permit a fair comparison, but I may point out that to eliminate even these small differences in weight, I have assumed that the electric locomotives would use only such portion of their adhesive weight as corresponds to the adhesive weight of the steam locomotive compared with it.



TRAIN WEIGHT EXCLUSIVE OF LOCOMOTIVE 300 TONS

	PACIFIC	DIRECT CURRENT	THREE PHASE
AVERAGE ACCELERATION UP TO 55 MILES PER HR. MILES PER HR. PER SEC.	0.266	0.288	0.423
MAXIMUM SPEED ATTAINED, MILES PER HOUR	68	59	68.5

Fig. 2.

This being strictly a comparison of acceleration characteristics, the period of acceleration was assumed to extend to a speed of 55 miles per hour only, so as not to be unfair to those locomotives having a very low rate of acceleration at high speeds.

In Fig. 2 a six-car train, weighing 300 tons exclusive of locomotive, was assumed. The steam locomotive uses its full adhesive weight up to 18.4 miles per hour, accelerating at 0.653 miles per hour per second. From then on the tractive effort drops according to the curve in Fig. 1, and the rate of acceleration correspondingly. A speed of 55 miles per hour is reached after about 200 seconds. The direct-current locomotive

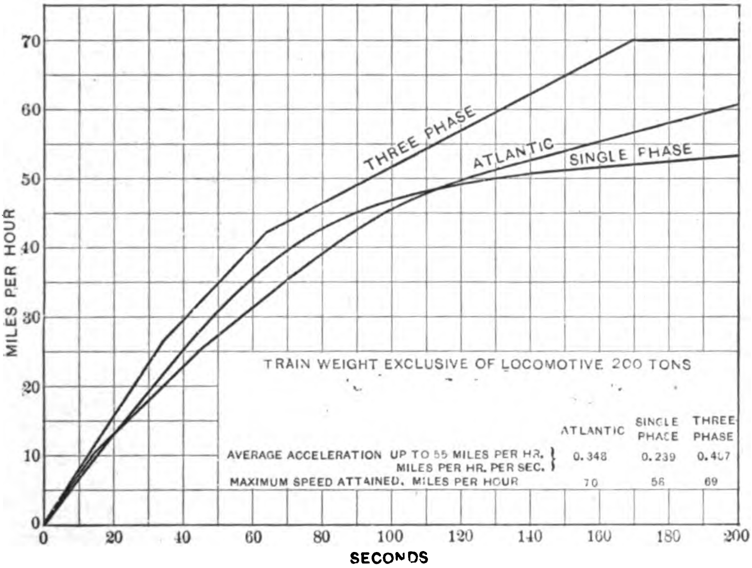


FIG. 3.

accelerates with 875 amperes per motor constant input, 2100 kilowatts maximum, up to 38 miles per hour, from which point on it accelerates on the motor curve at a constantly decreasing rate, until 55 miles per hour is reached, after about 180 seconds. The three-phase locomotive accelerates with a constant input of 2450 kilovolt-amperes, 2200 kilowatts maximum, with three different rates of acceleration corresponding to the three motor connections, reaching 55 miles per hour after about 130 seconds. The energy consumption for the direct-current locomotive and the three-phase locomotive is the same and equal to about 300,000 kilowatt-seconds.

In Fig. 3 where the train-weight is assumed to be 200 tons exclusive of locomotive, the steam locomotive again starts with the use of full adhesive weight, and although having at first a low rate of acceleration, it uses its great capacity at higher speeds to full advantage, and reaches 55 miles per hour after about 160 seconds. The single-phase locomotive and the three-phase locomotive start with the same initial input of 2,000 kilovolt-amperes, which, however, gives the three-phase locomotive a better initial tractive effort on account of its better power-factor and efficiency. After 33 miles per hour, the single-phase locomotive accelerates on the motor curve at a constantly diminishing rate of acceleration while the three-phase locomotive utilizes the same initial input up to full speed. A speed of 55 miles per hour is reached by the single-phase locomotive after about 220 seconds, and by the three-phase locomotive after about 115 seconds.

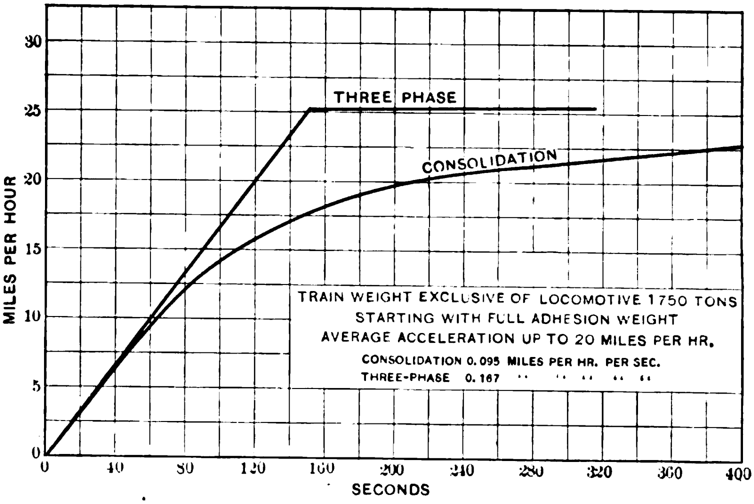


FIG. 4.

In Fig. 4 both the steam locomotive and the three-phase locomotive start with full adhesive weight and accelerate a 1750-ton freight train up to 20 miles per hour at the rate of 0.095 and 0.167 miles per hour per second, respectively, reaching 20 miles per hour after about 200 seconds and about 120 seconds, respectively. By reducing the input for the electric locomotive the acceleration period would be lengthened, but the performance would still excel that of the steam locomotive.

The three-phase locomotive seems, therefore, to be ahead of its competitors also in accelerating qualities, which is quite natural because it is the only one which can utilize a constant input up to full running speed. The three-phase locomotive is mathematically sure of reaching full speed after a certain predetermined time. Locomotives with series characteristics will approach full speed so slowly, that they very frequently do not reach it at all unless the distance between stops is very great.

CONCLUSION

The constantly increasing business on trunk and suburban lines will have as an inevitable result—track congestion. On certain railroads trains are now so heavy, and run at such high speeds, as to tax the capacity of the most powerful steam locomotives to the limit, and the headway between trains is as small as permissible. Here, then, electrification becomes an absolute necessity if the traffic capacity of the lines is to be increased without the tremendous expense of adding new tracks. We have seen that electric locomotives are in themselves more powerful than steam locomotives of even weight; but it is furthermore possible to couple two or more electric locomotives together by multiple-control connections, and to operate them for all practical purposes as one locomotive by one man. Thus an unlimited amount of power can be concentrated in one unit and traffic can be handled both in increased train weights, not limited by considerations of gradients, and also at higher speeds than are at present employed. That the three-phase alternating-current locomotive is by far the most suitable engine for this purpose I believe to have demonstrated above.

A. H. Armstrong: We have listened to the advocates of the 600-volt and the 1200-volt direct-current systems and the various alternating-current motor systems, and have learned that each of these types of motors possesses qualifications that permit the construction of an electric locomotive much superior to the present steam locomotive. It strikes me that each speaker uses his own individual method of saying the same thing—that we have in the electric locomotive a piece of apparatus which can accomplish results not possible with the present steam locomotive. We have outgrown the days of a machine having an indicated output under 2,000 horse power, a maintenance charge of eight to ten cents per locomotive-mile under the best conditions of level-track operation, and double this amount when the conditions are adverse; and we have at our disposal a locomotive that gave a maintenance charge of less than one and one-half cents per locomotive-mile during an endurance test of 50,000 miles, a concentrated output of 2200 horse power nominal, and fifty per cent. increase for unlimited periods by using forced ventilation. I believe that with the assets we have in the electric locomotive, the day has come when we can approach large railroad problems with supreme confidence of winning out over steam competition. It is not a case of the type of apparatus to be used, nor is it a question of frequency, as each case must be considered by itself in order to make the best individual showing for the local conditions involved. Ten years from now we will still be disputing over the question of frequency, alternating-current or direct-current operation, types of motors, and control to be used, etc. Looking back on the history of the steam locomotive, the same lack of agreement is apparent, and even to-day there is no standard type of steam locomotive receiving the universal approval of engineers and operators.

It is not necessary at the present time to standardize electric locomotives or systems of electrical distribution, as we have not yet demonstrated the best type of motor and the apparatus best suited to take care of the needs of both heavy and light electric railroading. No standardizing can be attempted without full experimental and operating data, showing without question that a particular type of apparatus is the survival of the fittest. I regret that no such full operating data are in existence to-day; in fact, no locomotive of the single-phase alternating-current or 1200 volts direct-current type is yet operating in commercial service.

The electric motor provides opportunity for doing something that cannot be accomplished by steam, and this is the reason why it has superseded steam power in the past and will continue to replace the steam locomotive in the future. It is not a question of petty economies effected; it is the broader question of increased facilities, increased gross receipts, and increased opportunities for earning money by means of the electric motor that makes it a successful revival of the steam locomotive. This point has been illustrated in the past by the entire elimination of the steam locomotive in urban and short-haul suburban work. It is being demonstrated in the big terminal electrifications now going on in and around New York. The managers of our large western roads are seriously considering the substitution of electricity for steam, based solely upon the fact that their roads are in need of a type of locomotive which can surpass the best performance of the steam locomotive as constructed to-day, or as foreseen in the future. A steam locomotive having a capacity of 500 tons trailing on a two per cent. grade is going to be a thing of the past as soon as full appreciation is paid to the fact that it can be replaced by an electric locomotive capable of hauling increased tonnage at double the speed. In face of such facts it is a matter of detail consideration to discuss the question of frequency and types of motive power when there are not sufficient operating data and experience at our disposal to enable one type of motor and one system of distribution to stand above all others as possessing qualifications demanding its universal adoption, and, hence, its standardization.

N. W. Storer: It seems to me that the whole question of the electrification of steam railroads comes down to one of dollars and cents, and the system that can be operated and installed for the least money will be the one to be adopted. As may be seen, there are many different ideas on the same question. Many engineers are working on designs of electric locomotives to meet the many requirements which are constantly being requested of manufacturing companies. I have worked over them for some time past, and every time a new proposition comes in, the matter of frequency, or alternating-current or direct-current operation must be decided. It is a question whether the problem can be solved by the simple direct-current system, which our friend the father of electricity, loves so well, or whether we must go to something higher and nobler up with our voltage and up in the air with our trolley. Our experience is that the decision is generally in favor of locomotive of the single-phase type. I have considered the direct-current locomotive, and the three-phase locomotive, prayerfully and carefully, but, it does not seem to me that either one of these is the type of locomotive which will meet the requirements of the railways of this country. The direct-current locomotive as it has been designed certainly will not do it. In speed characteristics, the single-phase locomotive pleases me much better than the three-phase.

The single-phase locomotive seems to offer the greatest possibilities. With it, we can not only operate up to what might be called the normal speed of a locomotive, but far beyond that. High speeds become simply a question of applying higher voltages from the transformer to the terminals of the motor. The same locomotive can be operated just as well at 10, 15, 20, or 25 per cent. above what might be called its normal voltage as the direct-current locomotive can be operated at it normal voltage. The question of commutation in the single-phase motor is not so much one of voltage as one of induction in the field, one of current which the motor is carrying or, in other words, of the tractive effort which it is exerting.

Every time a single-phase motor is designed for heavy work, the question of frequency arises, and it always works out much better for 15 cycles, for this reason: at least 30 per cent. greater output can be got from motors at 15 cycles than from motors of the same size operated at 25 cycles. That means that at the limit there must be 30 per cent. more motors if the motor is to operate on 25 cycles than would be needed on 15 cycles. That not only increases the cost of motors very much, but increases the cost of all mechanical parts, the motor-trucks must be heavier than trail-trucks—the entire equipment must necessarily be heavier.

The question of efficiency alone is bound to influence the matter very largely. The 15-cycle motor approaches closely the efficiency reached by the direct-current motor, and there is so little difference that it can hardly be detected. In power-factor it comes very close to the direct-current motor. It is above 90 per cent. throughout the entire range of loads in most sizes—it is practically unity.

The saving in cost of locomotives which might be effected by using 15 cycles instead of 25 cycles is mentioned in the paper, and I am bound to say that the difference which is shown is entirely inadequate to cover what in our opinion it would be. I should say that the difference would be at least $5,000, rather than $1,000. That makes a difference which seems to me to be overwhelmingly in favor of the 15 cycles; it is due largely to the number of motors.

In regard to the lighting of the cars, I believe that satisfactory lighting can be obtained with 15 cycles, by using a low-voltage lamp having a heavy filament. A lamp designed 15 volts, to operate on a 15-cycle circuit, will give just as good light and as perfect illumination as the ordinary incandescent lamp on a 25-cyle circuit. It will be entirely satisfactory for the lighting of cars. The many other questions which come up in connection with railway installations will of course influence the choice of frequency very largely, but as I said in the beginning, it is simply a matter of dollars and cents that will determine whether 15 cycles or 25 cycles is going to be adopted for railway work.

William McClellan: Having passed through the experience of equipping some cars with single-phase motors and proper multiple-unit control for 11,000 volts, I believe firmly that the solution of the railroad problem is going to be by means of the 11,000-volt system. Perhaps not exactly 11,000 volts, but a high-voltage overhead trolley with a single-phase motor. In spite of the fact that a heavier motor is needed for the power developed; in spite of the fact that the sub-station is separated into pieces carried on the motor-cars making a large amount of ton-miles in the course of a year—as a whole the system provides a better solution for trunk-line electrification than any other in sight at the present time. This is particularly true if engineers can be brought to think that 15 cycles is better than 25. I, for one, after a very careful examination of every argument, feel sure that nothing stands in the way of the standardizing of this frequency.

Although the steam railroads have not standardized as to details, they have standardized so that they can make necessary interchange of equipment. Electrical engineers must do such necessary standardizing at once. Unless this standardizing is done at once there might result one kind of trolley on this road running locomotives of one type, and another type on that road; this condition might not prove serious with electric locomotives, but if cars cannot be exchanged freely it will be impossible to electrify the railroads of the country, particularly on the grand scale suggested in this paper. So, therefore, I certainly agree that it would be advisable and possible to standardize immediately certain features of railroad practice, the height of trolley, the location of the third-rail, and the voltage and frequency at the trolley and third-rail.

In spite of the fact that the two great manufacturing companies in this country have different systems of control, I see no reason why the train-line jumper should not be standardized as to position and number of wires. That would solve a great many problems in itself, particularly if the jumper could also connect a heating and lighting bus-bar at a standard voltage, making thereby one jumper between the cars to be handled in addition to the air-brake connections. The largest jumper I know of has twelve conductors for the train line, and it is probable that this number is a maximum. Any particular system could use as many of these conductors as desirable. Such an arrangement would permit easy interchange of Pullmans, express cars, mail cars, fast-freight cars, etc., which might have to be used as trailers in multiple-unit trains of different systems.

The above features include all necessary standardization. This, I believe, is the only standardization that is possible or ought to be allowed at present, because anything else would stifle proper advance in the art.

The firm with which I am associated has always found it difficult to derive useful data from published information on costs of locomotive operation. Therefore, another scheme was adopted. It was to take several railroad divisions having different kinds of traffic, a division with large passenger traffic, another having large freight traffic, and another having a good mixed traffic, and if possible get costs on these. In this way we hoped to arrive at some general figures which could be relied upon. I am free to say that while we did have some success and did arrive at some results, on the whole they were unsatisfactory. It was difficult to obtain any reliable costs for coal, wood, and water stations; but the results given in the paper for maintenance of way and structures are as nearly correct as can be stated.

When we came to Item 12, all figures were very unreliable. I believe the only useful method is the one Mr. Murray has adopted of watching very carefully certain locomotives in service. One scheme we tried was to assume that we could substract the cost of boiler repairs and leave only engine repairs, and by some process of assumption get a comparison between costs of electric locomotives and steam locomotives. We found a pretty good agreement that boiler repairs were one-sixth of the total repairs of the engine, but we could find no railroad people who would agree in the assumption that an electric locomotive would cost anything less for maintenance than the machine part of a steam locomotive. Assuming the figures are the same, the maintenance on the electric locomotive might then be considered five-sixths of the present cost of the steam locomotive.

I ask you to beware of any figures given on maintenance by European railways, for the reason that labor is cheap in Europe; and secondly, a great deal of care is given to operation, and costs are likely to be very low. Neither can the cost of running a locomotive 50,000 miles, where it has been in the hands of trained electrical engineers, be taken as a comparative figure for a locomotive running day in and day out, put in the roundhouse at intervals, given more or less attention, but most of the time in the hands of a road engineer who may or may not be able to take care of it.

Some very interesting results were obtained in connection with Item 21. In the first place, I am confident that a "deadman controller" is as reliable as a second engineman, and makes his presence wholly unnecessary. In the second place, a very complete study by a prominent steam railroad man at several different roundhouses at which forty to sixty locomotives were handled per day showed a total cost per engine handled of $1.18. This included all operations from the time the engineman dropped his engine until he took it again. It was found that 54 per cent. of this was peculiar to steam, and could be omitted with electric locomotives. How much, however, would have to be added as peculiar to electric locomotives could not be satisfactorily estimated.

Forsaking figures, there are broad lines on which we may approach any railroad electrification problem and hope to solve it. These are:

1. The flexibility of motor equipment permitting multiple-unit operation for passenger and freight service in a variety of ways.

2. The possible increase in road-miles per locomotive on account of decreased time in roundhouse, etc. An average steam locomotive, making perhaps 3,000 miles per month in freight service, is about 45% of its time on the road, 30% in the roundhouse, and 25% in the yard awaiting orders, etc.

3. The possibility of generating power cheaply by locating the power plants close to coal mines, which will avoid hauling of the coal, and also by making use of large number of small water powers which, if properly developed, amount to a great asset for the railroad; water powers which would be of little use to an individual, but might be of great use to the railroad because its load is distributed over a large territory.

W. I. Slichter: I have been particularly interested in that part of the paper relating to the choice of frequency for single-phase railway work. I have studied the subject for some time and believe there is no question but that a lower frequency is very desirable for the single-phase motor.

There seems to be a unanimous opinion that the output of the motor may be increased some 30 or 35 per cent. by a decrease in frequency from 25 to 15 cycles. In many cases this will make it possible to build in the limited space available on the trucks of a car, a motor of sufficient power to perform the service required, whereas at 25 cycles it would be impossible to obtain sufficient power. But as Mr. Stillwell has pointed out, we must consider how much this change will cost. The other parts of the system, except the transmission line, are more expensive at the lower frequency.

The generator itself may be increased in cost anywhere from 15 to 50% depending on the size and design. This is due to the fact that a speed corresponding to 15 cycles will be difficult to obtain in turbines, while for slow-speed engine-driven units there will be no great difficulties.

Transformers are increased in cost about 20% by the change, while the distributing system will be decreased about 10% in cost.

Considering, first, an interurban road in which the amount of motive power is small compared with that considered for a large steam road as discussed by Messrs. Stillwell and Putnam, the relative costs of the various parts of an installation are fairly represented as follows:

	25 cycles	15 cycles
Generating station........	34.4%	38 %
Sub-stations..............	1.8%	2.1%
Low-tension construction..	14.8%	14.8%
Low-tension copper........	12. %	11. %
High-tension line..........	5.4%	5.4%
Bonding.................	7. %	7. %
Equipments and cars......	24.6%	23. %
	100 %	101.3%

For this interurban road then a 15-cycle installation would be more expensive.

But turning to a road which approximates steam railroad conditions, the cost of the equipment forms a much larger proportion of the total cost, while the increase in the cost of the power station is not so great on account of the larger size of the units. This transfers the balance to the other side and the figures are similar to those given in the paper. This shows that as we approach heavy railroad work the greater will be the need for the lower frequency.

It has not been pointed out, however that although the rated (one hour) output of the motor is increased some 35 per cent. by the change in frequency, this is only the output during acceleration, whereas the continuous output rating of the motor is not changed accordingly. For passenger service with long runs and a small percentage of acceleration, not as much is to be gained by the use of the lower frequency.

J. B. Whitehead: As I have listened to the discussion, a certain aspect of the question has suggested itself, and I venture to bring it forward. In considering an electrically propelled vehicle, I take it we may consider that vehicle best which possesses two characteristics to the greatest degree, other things being equal; and these characteristics are the degree to which the vehicle is self-contained and the greatest power that can be got into the space given to the motors. In speaking of the degree to which an electrically propelled vehicle is self-contained, I wish to draw attention to the fact that we may consider an electric locomotive or car more self-contained so far as it requires less attention from the outside. That is to say, the greater the distance between sub-stations and the less complicated the apparatus at the sub-stations, the better. In these respects the alternating-current has the advantages of the direct-current. If the advocates of the direct-current system, could bring forward apparatus that would operate and transmit at the same voltages that the alternating-current system does, a great deal of this discussion would not have taken place. From the standpoint of self-containment, I think that we must look for something from the direct-current side before we yield the position taken by the advocates of the alternating-current system.

It has been very interesting to hear the comments on the other aspect, the greater power which can be got into the space available for motors by reducing the frequency. If 15 cycles is the point at which the advantage of an increase of power within this space stops, being offset by the greater weight and greater cost of transformers, and the difficulties in the generating apparatus, then that is the frequency that will finally be adopted.

The problem is to do the right thing in the right way; and if we can stretch out more and more the distances between the points where the motor needs help from outside by using the alternating-current system, then the alternating-current system will prevail. The footnote suggests a danger from the rising potential of a broken bond, in the case of high-potential operation. I ask if there is any instance on record where there have been unpleasant results attendant upon a broken bond?

L. B. Stillwell: First, I shall reply to Mr. Whitehead's question. We have assumed in our estimate a No. 4/0 conductor in the track circuit in order to aviod the possibility of a dangerous potential on the track in case of broken bonds. My attention has never been called to any case in which danger has occurred from this cause, but it appears to me a theoretical possibility and we desire to make our estimates eminently fair to the steam side of this proposition.

I have been greatly gratified by the discussion on this paper, and I hope that members of the Institute who have additional concrete facts bearing upon the important question of frequency will contribute these facts by letter.

It is evident that the great majority of engineers present would admit that the question of frequency is settled decisively by the testimony we have had in favor of 15 cycles. The testimony of Mr. Lamme, the inventor of the single-phase motor; of Mr. Storer; of Mr. Slichter, and other men who have been active in their development and practical application, to my mind is conclusive as regards the performance of the motor and they have testified that the difference in favor of 15 cycles, as measured at the draw-bar, is approximately one-third. When this fact is taken into consideration, in view of the general perspective of the problem, which we have endeavored to establish by considering the electrification of our railroads as a whole, it seems to me there is only one conclusion to draw.

In our estimates we calculated that the expenditure for electrical equipment of rolling stock, if the 25-cycle system were used, would approximate $450,000,000. Mr. Storer has stated that the difference in favor of 15 cycles would be at least $5,000 per locomotive, but his figure for the entire locomotive is considerably higher than that which we have assumed in our estimates, and therefore we may scale this $5,000 down to about $4,000. Applying this to 24,000 locomotives, the difference in favor of 15 cycles is $96,000,000, which is ten times the difference in cost of the power-house equipment which is adversely affected by a reduction of frequency.

I believe that to-day we are able wisely to standardize frequency as well as the position of the overload trolley. These things certainly should be agreed upon. The steam roads have standardized everything essential to the interchange of their rolling stock. We must follow that precedent or we shall get involved in all sorts of trouble.

Mr. Sprague is in favor of the direct-current system. He has done so much in the development and application of electric apparatus for traction purposes, first by the direct-current motor and more recently by the multiple-unit system of control, that I should be very sorry to see him make a serious mistake, and I hope that before he nails his flag to the 1500-volt direct-current masthead he will take into account all the evidence presented to-night.

Frank J. Sprague (by letter): Commenting briefly on some statements made by various speakers, which in one breath describe the perfection of results attained by 25-cycle motors and yet complain of their lack of capacity, I am reminded of a sign which I often see in the Subway cars: "We could not improve the powder, so we improved the box."

My criticism of the 25-cycle motor, which has been so well exploited, has not been because of the potential at which a trolley line must be operated. The relations of potential to size of conductor are really of such common knowledge in the primer classes of electrical engineering that it is hardly worth while to discuss that particular feature. Obviously, if alternating currents are to be used then just as high potentials as the physical facts will permit should be adopted, and there is nothing revolutionary in the use of 11,000 instead of 3,000 volts.

Capacity is the keynote of an equipment, and capacity is not measured alone by that of conductors, but ultimately also by motor equipments; and the entire testimony of this evening bears out my criticism, that the 25-cycle motor as constructed to-day does not under like conditions approach the capacity of the direct-current motor. It is proposed to increase this capacity of lowering the frequency. This, also, in itself is not a novel proposition, for it has been discussed for a number of years. It involves a good many questions, some of them going back to the central station. It may be advisable in the end to adopt for alternating-current operation this periodicity, and I ventured months ago to predict that the largest 25-cycle railroad enterprise now carried on would adopt a lower frequency.

In view of the fact that reduction of frequency, which brings a motor more nearly to direct-current conditions, is now acknowledged and advocated as an essential, I find some difficulty in reconciling myself to that subtle reasoning which holds that because a motor is to be run on a part of its route from direct-current supply it is better that it should be designed for the higher frequency.

While in entire sympathy with every practical development, I care not by what means or along what lines, I have opposed, and will continue to oppose any basis of camparison which assumes as worthy of the fullest credence any and every claim made for single-phase alternating motors, while denying either the possibility, practicability, or importance of the utmost development along direct-current lines, whether used for overhead or third-rail construction.

During the last 19 years I have advocated many radical developments on the floor of this Institute, with what results the gentlemen present are familiar. Now, rightly or wrongly, my name is particularly identified with efforts toward higher voltage direct-current operation, even with the third-rail. I willingly accept the sponsorship of that development, and in answer to Mr. Arnold venture to assert that, so far as public sentiment or restrictions are concerned, while it is quite possible that the continued introduction of an exposed top-contact third-rail will be condemned, as it ought to be, it is quite as likely that high-voltage overhead lines, often in close proximity to highway bridges and crossings, and in possibly dangerous proximity to the general public at city terminals, will come under the ban as that a well protected under-contact third-rail will do so.

Further, I will take direct issue with Mr. McClellan, and venture to prophesy that third-rail installations will still proceed with a good deal of regularity.

I am quite sure that many of the critics of the direct-current development are not as familiar as they might be with what has been done in this line within the last year or two, especially in commutating-pole construction and gearless motors. The former, one of my early babies, and now a vital feature in single-phase alternating-current motors, has been reduced to practice with direct-current motors with such success that I fully confirm Mr. Potter's statement as to its efficiency. To my personal knowledge, four-pole motors of this type, varying from 40 to

240 h.p., normal hour capacity, will operate, so far as commutation is concerned, at excess voltages of 75 or 100% with entire freedom from all commutator disturbance. This improvement alone is one of the most remarkable in electric motor construction in recent years; and directly dependent upon it is the possibility of a return to my earlier methods of varying speed and torque of a motor by varying the field-magnet strength, a principle now in common use in variable-speed shunt motors, and which is equally applicable to series machines. This addition of a shunt to the series field has an important bearing upon the comparisons made by Mr. Muralt. The series motor is no longer a machine with a fixed curve, but one with a very wide range of speed and torque control.

In connection with the other important developments, it would be unjust to omit mention of that modest engineer, Mr. Batchelor, who, Columbus-like, by one bold stroke created a departure in gearless machines, individual to direct current work, which is of the utmost importance, and which has received its very practical proof and demonstration, much to the surprise of many critics in this Institute, in the locomotives recently built for the New York Central Railroad.

As most of you are aware, these are gearless machines in which the previously accepted axiomatic principle of fixity of relation between field and armature was abandoned, the latter being mounted directly on the axle, and the fields being carried upon, and as an integral part of, the locomotive frame, supported by its springs and hence moving freely, irrespective of the armature. Not only gears, but armature and axle-bearings are all dispensed with, and the acme of simplicity in motor construction reached. If desired, the armatures of course can also be springborne.

It may interest those who have somewhat cynically questioned 1200-volt direct-current operation, to know that the General Electric, the Westinghouse, and the Electro-Dynamic companies have all either taken, or bid for contracts requiring the use of motors at this potential.

On the matter of standardization, perhaps I can add a few words. To a certain extent some things take care of themselves. The height of a trolley wire is dictated by the necessity of a clear height above a man on a freight car, and is about 22 ft. There can, of course, be considerable variation from this without in any way interfering with actual operation. The location of the third-rail, with center 28.25 in. from the gauge line, and with a working surface from 2.75 in. to 3 in. above the rail, has been practically accepted, as per suggestion sent out a long time ago by Vice-president Wilgus of the New York Central Railroad as chairman of that road's electric commission.

I suppose I ought to feel flattered to see the universal testimony to the benefits of multiple-unit operation; but some of the speakers outdo the parent in love for his child, and have committed themselves to recommendations of an extreme character. Here, too, there is little to be said in the matter of standardization. I settled that nine years ago when I created a train line composed of sections carried upon, and terminating in couplers on each car, and joined by reversible jumpers between the cars—all constructed, connected, and located so that cars could be connected up in any required order, number, or sequence, and indifferently as to end-relation; and the master-controllers connected therewith had like characteristics with reference to track movement. One of the essential features of this train line is the relative location of speed- and direction-controlling wires, the former unchanged in any connection, and the latter reversed in connection when cars are reversed. Would-be improvers departed from the essential five-wire system, abandoned automatic control, and introduced for a time additional individual wires for various rheostatic steps in the speed control, as on the elevated railway in this city; but the progress of events is carrying them all back to the original lines which I laid down. Practical experience, however, leads me to oppose the introduction into a train line of wires for trunk-line connections, heating, lighting, or brake-control.

I am not able to get up any enthusiasm about a proposition to equip the freight cars of the country with train lines. While the control of two distantly placed freight locomotives would at times be useful, it is not vital, nor are there the same reasons which make simultaneous control of motor cars in passenger trains essential.

Certainly no train operation would be conducted without competent men on locomotives which are distantly removed from each other. Moreover, in view of the universal interchange of freight cars, even if the majority of them were equipped with train lines the introduction of a single one without such an equipment would make useless the balance, and the switching necessary to avoid this would be objectionable. The possible advantages of such an equipment are vastly more than offset by the enormous cost.

Calvert Townley (by letter): The tabulation of distributed opertaing costs of steam roads, contrasted with the estimated costs which it is expected will obtain when steam roads shall have been electrified, is interesting, and the conclusions reached are in line with what electrical engineers very generally believe. I am not sanguine that this tabulation will be given material weight by the men whom it is most desirable to convince; namely, the steam railroad operating officials. Such men, as a class, attach, and properly I believe, much greater weight to statistics showing what has been accomplished than to any figures showing what it is expected will be accomplished, no matter how logical these latter figures may be, or with what care and satisfaction to the compiler they may have been prepared. It is also perhaps unfortunate that in the comparison of the operating costs, the authors of the paper should have omitted any figures on fixed charges. Naturally, such charges, resulting as they would from investments needed to electrify, will increase the total expenditures under electric operation, and will act to offset in varying degrees the estimated savings which Messrs. Stillwell and Putnam have taken. To the man who is unable to estimate what will be the investment required to electrify, this may unfortunately be interpreted to indicate a dread on the part of the electrical engineer that a complete comparison of all expenditures for both methods of traction should be made. There is, furthermore, a deeply rooted feeling that the depreciation in electrical equipment due to the replacement of one type by another, so-called amortization, is much higher than is the case with steam equipment, and there is only one way by which such conviction is likely to be removed; that is, by the actual demonstration in practice that the amount chargeable to amortization is small.

With the principle enunciated by Messrs. Stillwell and Putnam on standardization, I am thoroughly and heartily in sympathy; but in the words of an engineer with whom I discussed this matter, I believe we should only undertake standardization when we have something to standardize. Standards are artificial only to a limited degree, and no edict of the Institute, or of any other body, can successfully long maintain a so-called standard against something better, or when greater advantages can be obtained by departing from the avowed standard. I cannot but feel that the Institute would lay itself open to serious criticism if it should undertake, for example, to establish a standard frequency for electrically equipped steam railroads, when there is no single electrified steam road in this country operated by single-phase current. Particularly would this be true if they should adopt a standard different from every single-phase trolley road now in operation, or in process of being equipped in this country, and having as a basis for such adopted standard only the calculations and experiments of the engineers of the manufacturing companies, extending over but a short period of time. The best type of equipment for the electrification of steam roads will ultimately prevail; but it will prevail by practical demonstration as to its fitness, and in no other way. I should regard it as far better that a few railroads should spend some extra money in later changing the equipment which they may have adopted, rather than that some important development in the art should be hampered or prevented because of a decision made now on insufficient evidence. If the authors of this paper should now advise their clients to adopt something which later may be found to be one of the "discards from the deck," they would only have taken a chance which other engineers have taken before, are taking to-day, and must continue to take for some time to come.

With respect to the advantage of 15 cycles or any other modification of a standard frequency that may be suggested, the burden of proof obviously lies with those advocating the change; to receive serious consideration, reasons for the change must be weighty and the evidence supporting them fairly conclusive. In the present instance, the arguments advanced in favor of 15 cycles are essentially two: first, the lower frequency permits a lighter and more compact motor; and secondly, the induction in the line and track are reduced. Of these two reasons, the first is advanced as the controlling one. Every other consideration is confessedly adverse. It is, therefore, pertinent to inquire, in fact we must know, to consider the subject intelligently, how much smaller, lighter, and cheaper the lower-frequency motor is to be. In undertaking to procure this information, however, we are at once confronted with embarrassment. There being no 15-cycle equipments in existence in this country it is not surprising that the Westinghouse engineers hesitate definitely to predict what will be their relative weight, cost, etc., when they shall have been constructed to meet the necessary widely varying specifications that will certainly be forthcoming as soon as the electrification of steam roads is fairly under way.

In considering the electrification of the N.Y.N.H.&H.R.R. Co., plans were submitted by the Westinghouse Elec. & Mfg. Company for both 15- and 25-cycle passenger locomotives designed to perform identically the same service. Here, then, we have a definite statement of the relative characteristics of the two types applied to a concrete case, and carefully worked out. The figures include, moreover, not only a comparison of motors, where the 15-cycle is lighter, but also of the transformers, where the 15-cycle is heavier, and, further, of the other parts of the locomotive, which are affected variously and in different degrees. It was found that the 15-cycle machine had the advantage of 5.2% in weight, about 3% in cost, and was slightly better as to its efficiency and power-factor. I have been told that the specifications in this cases were not such as to permit full advantage to be taken of possible 15-cycle construction, but the specifications imposed absolutely no limitation in this direction that was not fixed by the operating conditions. I am further advised that there have been subsequent improvements in 15-cycle motor design that now warrant better claims for it, and that in consequence the present difference of weight of locomotives may perhaps be nearly 10%, or, in some cases, and under varying conditions favorable to 15 cycles, even more.

If the locomotive weight may be said to average 30% of the total train weight, the use of a locomotive weighing 5.2% more will add 1.56% to the total train-tonnage. Similarly, ten per cent. increase in locomotive weight will add 3% to the total train-tonnage. In freight service the ratio of locomotive weight to train weight being less, the increase in total tonnage due to additional locomotive weight would be correspondingly smaller. These additional weights, while undoubtedly undesirable, could hardly be considered controlling or as constituting a sufficient offset to the serious objections of a change in standards, even if such change were not coupled, as it is, with the attendant disadvantages to power station construction in lighting, and in the use of auxiliaries of all kinds.

The statement that there have been recent improvements in 15-cycle motor design is interesting as an indication that the last word in single-phase motor design has by no means been said; indeed, it would be a most remarkable condition of affairs and decidedly contrary to the history of every other electrical development were it otherwise, whether the motor be designed for 15 cycles or for any other frequency.

In the light of these facts, with our high-priced prosperity labor and a soaring material market, it is obviously dangerous even to attempt to state the difference which we may reasonably expect will obtain between the cost, for example, of motors of two different frequencies when the dust settles. On this account it appears to me impossible seriously to consider or to attach much weight to the comparative-cost figures presented by Messrs. Stillwell and Putnam for the possible future electrification of the entire railway sytems of the United States.

In this connection it may be proper to point out a future possibility that has not been touched upon, but which may prove to be an important factor in the frequency question. An engineer who has been familiar with trolley practice only, and who studies steam railroad electrification for the first time, may be pardoned if he is surprised as the comparatively small amount of power required by the steam, and he is likely to be further astounded, and perhaps appalled, at the high peaks and wide fluctuations in load. These conditions do not make for the economical generation of power, but on the contrary impose an abnormally heavy fixed charge to cover capital sufficient to handle peak loads, and an unduly large operating cost for the additional force necessary to operate a station to handle peak loads, the average output of which station is, however, but a small per cent. of its capacity. It is possible that Messrs. Stillwell and Putnam had this feature before them in suggesting the distribution of power 150 miles in each direction from centrally located power houses. However, I am not able to justify the general adoption of such a plan, either on the score of expense or of reliability, though there may sometime be found a particularly favorable case where power can be generated from steam and economically transmitted this distance. I am confident, however, that a much smaller initial investment will be required, and a considerably lower operating cost will obtain, if smaller stations are installed at much more frequent intervals. I believe that such a plan will be found more economical, even with the reduced load-factor thereby entailed. But the question of load-factor brings me to the future possibility above referred to, which is this: as soon as the railway manager discovers that in order to make cheap power he must make it in larger quantities than his road can use, and that his station must also have a good load-factor, he will utilize his good railroad credit in the direction of establishing larger power plants than he himself needs, and he will sell quantities of cheap power to neighboring industries, thereby affording them the advantage of such power at lower rates than they could themselves produce it, and securing for himself, not only cheap power for his own use, but a profit on the sale of the surplus.

Twenty-five cycles is a standard and a satisfactory frequency for induction motors in industrial establishments and for synchronous converters where direct-current trolley systems are in operation. Fifteen cycles is likewise applicable to such service but is concededly not so good, and it is not at present a standard. Should it become so, the cost of transformers for use with it will be materially greater than the cost of transformers for 25 cycles—perhaps somewhat in the neighborhood of 40% more, and the frequency is not one that affords as great a flexibility in the speeds of the induction motors supplied by it.

In the light of the foregoing, the following seem to me clear:

1. That it would be wrong to undertake to establish a standard frequency for single-phase railway operation at the present time.

2. That even after it has been credited with all the estimated advantages claimed for it, a 15-cycle frequency has not yet made out a case entitling it to general preference.

Ralph D. Mershon (by letter): It seems to me that we should go slowly in the matter of adopting a standard frequency for traction work. The reasons for caution in this matter are pretty well set forth in the paper, but there is one of the considerations touched upon which will, I believe, before long have considerably more weight than at present. This consideration is that of the use of induction motors for traction purposes, especially motors whose speed characteristics may be varied by a change in the number of poles, In the case of such method of speed-control, a higher frequency than 15 cycles is desirable as giving greater flexibility in the range of speed. It seems to me it would be much better to wait until the lines of development of traction work are more clearly defined than at present before adopting as standard a frequency lower than 25 cycles.

H. M. Brinckerhoff (by letter): The wide field covered by this timely paper and the broad lines on which the authors have laid out their general argument deserves a much more careful analysis and discussion than was possible at the meeting at which it was presented. A brief written contribution, giving some additional data upon some points contained in the paper or referred to in the verbal discussion may therefore not be out of place.

The first of the four points enumerated by the authors; that is, " the record of certain facts relative to heavy electric traction which have been established by experience " brought out in the discussion various references to one of the items that might be further elaborated upon.

The record of the results obtained on the Manhattan Elevated, Subway, and various interurban railways are used as a basis of comparison upon which to estimate operating costs for steam railway electrification. One of the most frequent criticisms offered by steam railway men is that the period of operation of electric installations has been too short to show fully the cost of repairs and renewals, such as are found in similar items in long established steam railroad operation.

The earliest heavy electric railway system is the Metropolitan West Side Elevated Railway in Chicago, which was the first to operate commercially with the third-rail. Starting in April 1895, nearly twelve years ago, it operated with one motor car per train until 1905, then the multiple-unit control was adopted and a second motor car used on four and five car trains, instead of one as previously.

The total cost of operation per car-mile on this road, starting at about $0.075 in 1896-7-8, showed small fluctuations up to 1905, when it was $0.0931, the highest single year being $0.0971 and the average for the ten years $0.0836. Here then we have a system in its tenth year showing a cost per car-mile for all expenses, omitting taxes only, which compares with the steam locomotive operation of the South Side Elevated of Chicago of $0.106, the Lake Street Elevated of $0.1174 and the Manhattan Elevated of New York of $0.1198 per car mile. The increase noted for electric operation on the Metropolitan from 1895 to 1905 is partly accounted for by considerable increases in rates of wages and cost of fuel and general supplies.

As the writer was connected with this road from the start, and general manager for six years prior to 1906, he states on his personal knowledge that the tenth-year costs included renewals in all the items—ties, rails, frogs, and switches, repainting cars, renewals of armatures, commutators, gears, pinions, and all the various items that might be said to have a considerable first life. The fear very naturally entertained at first, that after a certain period the renewals would become excessive, has not been realized, even after a ten years' term of constant heavy service. The costs are greater the tenth year than the first or second, but are still 25% or 30% below corresponding costs of similar steam locomotive operation. At the same time the service has been immensely improved in speed, frequency, and general desirability.

While it is difficult to compare electric car-mile statistics with steam railway train-mile figures, the facts here noted certainly support the contention of Messrs. Stillwell and Putnam for operating costs at least 20% lower for electric than for steam operation under favorable average conditions.

In using the general average results in the carefully prepared tables of statistics presented by the authors, the danger of applying general averages to specific cases should be clearly pointed out. An average is simply the mean value of two or more amounts, and this average value may vary so greatly from some individual figure on the list from which it is derived as to make a specific application based upon it very misleading. General averages are valuable for general broad considerations, but specific cases must be analyzed and determined upon in their individual conditions.

In their estimates of the costs, the authors have assumed the universal use of single-phase alternating-current apparatus. In the discussion at the meeting it was contended that this assumption was too radical, since no single-phase installation of this character has begun actual service. On the other hand, some speakers criticised the idea and use of the third-rail system as out of date. All past experience shows that a radical innovation is not in itself necessarily bad, neither should an existing successfully operating system, whose limitations have been demonstrated under service conditions, be broadly condemned on these points alone. The present existing heavy electric traction systems are the result of development along a line radically differing from the previous lighter forms of street and other railway apparatus, but this has not prevented the enormous extension of the older lighter form in the field for which it is adapted.

As the writer happened to be engaged upon the design of the original third-rail installation for the Intramural Railway at the Columbian Exposition in Chicago during 1892-3, and joint patentee of the various devices then developed, he feels authorized in saying that no claim was then made that *the only true and correct solution of the electric railway problem* had been evolved. Certain conditions had to be met—a light elevated structure of limited dimensions and clearances, trains of four cars to carry dense passenger traffic, with stations close together, and demands for the highest possible speed and regularity of operation.

This problem was then absolutely new. That the system was evolved, the apparatus designed, installed, and put in operation in less than eight months, and fourteen four-car trains on a line about three miles long, carried successfully from 100,000 to 125,000 passengers in days of 14 to 15 consecutive hours, does not call for any apologies from those connected with this work.

The use of the third-rail itself was brought about by the necessity for collecting large amounts of electric current from a stationary conductor by apparatus attached to moving cars. The decision to use a large cast-iron shoe sliding on a steel rail was met with many predictions of failure; the result is a matter of history.

The problem met in 1893 is presented to-day, changed only in magnitude. The solution then evolved accomplished its purpose so successfully that in the year 1906 the third-rail system of the U. S. hauled close upon 700,000,000 passengers, at a cost fully 20% below what it would have been with steam.

The writer does not wish to be understood as advocating the whole sale installation of the third-rail on all the steam railway systems of the United States. It has a field, however, of its own which it is occupying successfully. That it has been found to have objectionable features in certain cases is not surprising; on the contrary the variety of conditions which it has successfully met is rather remarkable.

When we discuss the broad problem of electrifying trans-continental railway systems, the added magnitude of the problem involves the further conditions of great distances and large and infrequent train units. The obvious course to pursue under such conditions is to raise the voltage on the working conductor, and that this involves overhead contact is very apparent.

In examining the many forms of alternating-current single- and three-phase lines in Europe last winter, the writer could not but help noting a number of details which are pertinent to this discussion. The use of the relatively high-voltage trolley is successfully accomplished and the insulation of the high-tension-side of the apparatus on the car is not seriously troublesome. It is also true that a system like the Valtellina Line in northern Italy performs all the functions of a steam railway system. Trains of through freight, local freight, express passenger trains, local passenger trains, excursion and specials are run, with interchange of cars and traffic, with the steam railway systems of the country.

There are some points upon which we must be on our guard, however, in making comparisons. Continental railway road-beds are very superior, as a rule, to the average in America, nor have they the immense and complicated freight-yard layouts and intricate switching problems seen on our lines. The cars are much lower and very light compared with our freight, passenger, and Pullman cars. Wages are much lower and the demand of the public as to quality of service not so severe.

All these must be allowed for in using their cost figures. What they have accomplished in various lines is very instructive and interesting, and it is flattering to know that the incentive vigorously to develop single-phase railway equipments now being pushed by some of the largest firms in Europe came from reports of American effort in this line.

The authors' third point: "Importance of Standardizing Electrical Railway equipment as rapidly as may be consistent with progress" is certainly timely and well taken. Upon the assumption of ultimate universal electrification of the entire railway systems of the country, it is well to note that the interchangeability at present effective on the steam railways does not mean actual identity of apparatus, but sufficient similarity to insure coupling, hauling, heating, and renewal of parts such as journal brasses, etc., upon all lines.

As there is now a variety of types of locomotives on connecting systems and these are operated, generally speaking, on their own lines, so it should be possible to operate through passenger and freight business entirely by standardizing the few items mentioned, and yet retain the advantages of motive power apparatus of different types specially suited to meet certain local conditions.

The great flexibility thus far shown in the development of electric railway apparatus, such as the use of the third rail on private right-of-way and overhead trolley upon streets; and running alternating current on one part and direct current on other parts of a line with the same cars, are only indications of the possible interchangeability of systems of apparently hopelessly divergent characteristics. The two classes, freight and heavy Pullman or passenger cars, are, broadly speaking, the through equipment. On neither of these is it likely to be found desirable or economical to install individual motor equipment and multiple-unit control. The local and suburban trains, with multiple-unit control, will not leave the parent system. Interchangeability then of the *through equipment* does not prevent the selection locally of the most desirable motive power system, provided the present degree of standardization common in steam railway practice is adhered to.

During the present period of development and adjustment of electric traction to steam railroad conditions, the existence and advocacy of different types of apparatus brings to the problem a spirit of emulation and competition that is tending to greater perfection of detail and much more rapid progress than would be the case were all engineers working on a single type. The fact of honest difference of opinion by men striving to meet certain specific conditions successfully is not a sign of weakness as some doubters would have us believe, but a strong argument for the broad applicability of electric power.

A. H. Babcock (by letter): The salient points of the paper seem to me to be the statement that the alternating-current equipment is the only class of equipment deserving serious consideration in connection with the general problem of heavy traction. the question, " where ten years from to-day, will be the 1200-volt of 1500-volt direct-current system? " and the plea for standardization of 15-cycle apparatus.

It is to be regretted that at present there is not available any detailed information covering the actual operating data (such as follows) on the few single-phase roads now in operation. In one of the cases that has come under my personal notice, three passenger cars and two work cars are operated. The passenger cars are equipped with from 100 h.p. motors and weight equipped, but not loaded, 40 tons. The work cars have four h.p. motor equipments and weigh somewhat less. Power is purchased at three phase 60 cycles, is converted to single phase 25 cycles, is metered and paid for at the rate of 1½ cents on the three-phase side of the converting set. Measured here, the following figures were obtained for one month's operation last fall.

Average tonnage per car operated	36.25
" watt-hours per ton-mile	153
" cost of energy per car-mile	6.92 cents.
" kilowatt-hours per passenger car-mile	6.12
" cost of energy per passenger car-mile	7.65 cents.

It should be noted that the foregoing figures are for power alone, without any fixed charges or other expense. With a total of five cars of all kinds under operation, eight men including the foreman, were needed and employed in the car house on motor-car repairs, with two more men available for emergencies.

Is this sort of thing " the only class of equipment deserving serious consideration in connection with the general problem which we are discussing? "

If this road had been equipped with 1200-volt direct current, under the same operating conditions and losses in transmission as are now made, the energy per ton-mile would have been 107 watt-hours as against the 153 actually recorded, and the monthly cost of energy would have been reduced in proportion.

It is safe to say that the 1200-volt or the 1500-volt direct-current system will be heard of in ten years, if the single-phase system is not developed far beyond the inefficient case cited above.

With reference to standardizing 15 cycles, it may be remembered that the first installation proposed called for 16⅔ cycles. Afterward 25 cycles was made the standard in order to fit existing apparatus, and we were informed that the change in frequency made no difference. Now we are informed with equal positiveness that 15 cycles is to be the panacea, and this in spite of the fact that not one 15-cycle installation is in operation in this country. An engineer responsible for the expenditure of large sums of money may well hesitate about standardizing anything in a field where the very first development has yet to be made and proved.

It is not my intention to appear to condemn the entire single phase system on the showing of the one road the operating costs of which have been investigated by me; nor is the fact that 1200-volt direct-current motors have been specified by me for a large suburban service to be taken as a declaration in favor of high-voltage direct-current as a substitute for single-phase in all cases. The right is reserved to choose for every specific case the type of apparatus best adapted.

All engineers in a similar position must regret the absence of published accurate disinterested information on the operating costs of the few single-phase roads now in operation.

W. S. Murray (by letter): Upon the belief that the two departments in which the greatest economies to be derived in electric versus steam operated trains are fuel and locomotive repairs, it has been my effort during the past eighteen months to secure absolutely reliable data in these two departments of cost concerning the steam operated trains of the New York Division of the New York, New Haven, and Hartford Railroad Company.

FUEL.

Ton-miles are produced in several classes of service, viz:

1. Passenger express.
2. Passenger express-local.
3. Passenger local.
4. Freight.

TABLE 1.—EXPRESS PASSENGER SERVICE.

No. of Locomotive.	Mileage of locomotive in 18 days.	Pounds of coal burned in 18 days.	Average weight of train, including locomotive and passengers.	Total ton-miles of train, including locomotive, passengers, and switching for 18 days.	Total horse-power hours for 18 days of locomotive in revenue service based on average h.p. between Woodlawn and New Haven.	Pounds of coal per indicated h.p.-hour based on average indicated h.p. between Woodlawn and New Haven.	Total revenue ton-miles of train, including passengers and locomotive for 18 days.	Pounds coal per revenue ton-mile.	Pounds coal per indicated h.p.-hour by average ton-mile method.
832	2,782	301,384	573.5	1,556,730	73,100	4.12	1,545,000	0.195	4.40
841	2,336	215,830	480.7	1,123,050	53,150	4.06	1,123,000	0.192	4.34
Avg.	2,559	258,607	527.1	1,339,890	63,125	4.06	1,334,000	0.194	4.37

LOCAL EXPRESS PASSENGER SERVICE.

1262	3,160	295,038	303.0	914,330	63,900	4.62	894,000	0.330	4.54
1258	2,644	264,138	302.2	795,182	57,000	4.64	794,500	0.330	4.54
1272	3,482	353,396	351.5	1,147,520	80,000	4.42	1,114,000	0.317	4.36
1571	1,890	187,180	307.8	577,929	40,600	4.61	566,000	0.331	4.55
1574	1,938	216,583	306.4	593,838	42,500	5.10	593,000	0.366	5.04
Average	2,623	263,267	314.2	805,760	56,800	4.68	792,300	0.335	4.61

An interesting and valuable query is, what fraction of a pound of coal is consumed in producing a ton-mile in any one of the above services? Tables 1 and 2, following, show that it takes 0.169 lb. of coal, 0.194 lb. of coal, and 0.335 lb. of coal to produce a ton-mile in freight, express passenger, and express local passenger service, respectively.

It will be further noted that in the above tables there is given the pounds of coal required per indicated horse power hour for the passenger service. The ten heads under which the compilation of these tables were made show, in order that these data be absolutely reliable, the following conditions must be satisfied:

1. Exact mileages measured.
2. Exact weight of tonnage hauled.
3. Exact weight of coal burned.
4. Maximum continuous number of indicator diagrams taken to determine indicated horse power.
5. A sufficient number of days of continuous test to assure average results.

1. *Exact Mileages Measured.* The zone over which the test was conducted was the New York Division of the N. Y. N. H. & H. R.R. Co. and all trains runs had specified terminals within the zone, the mileages of whch are measured.

2. *Exact Weight of Tonnage Hauled.* The engines, twenty in number, and all cars included in the test were in the regular log of the mechanical superintendent and the superintendent of car service, with measured weights.

TABLE 2.—FREIGHT SERVICE.

No. of Locomotive	Mileage of locomotive in 18 days	Pounds of coal burned in 18 days	Average weight of train, including locomotive	Total ton-miles of train, including locomotive, for 18 days	Pounds of coal per ton-mile
300..........	1,557	230.376	930	1.446.868	0.159
301..........	1,153	184,836	661	761.755	0.242
325..........	1,592	231.366	696	1.108.615	0.209
373..........	2,010	237,006	1,060	2,129.575	0.111
382..........	2,018	304,044	1,240	2,495,072	0.122
386..........	1.274	220,680	731	930.792	0.237
448..........	2,272	413,106	1,255	2,850,046	0.145
453..........	2,350	255,444	872	2,053.142	0.124
Average......	1,778	259.607	931	1.721.983	0.169

3. *Exact Weight of Coal Burned.* Each of the twenty engines coaled from an individual car, the weight of the coal therein being measured immediately before and after the test, the coal cars being placed at the regular coaling points of the locomotives.

4. *Maximum Continuous Number of Indicator Diagrams Taken to Determine Indicated Horse Power.* A continuous set of indicator diagrams were taken on a locomotive for both express and express local runs between Woodlawn and New Haven. A wind-shield was erected over the left cylinder of the locomotive, and the following scheme of indication adopted, viz:

a. One minute allowed for changing cards on steam indicator.
b. Six diagrams per minute to be taken on the same card.

c. Two minutes to be devoted to taking cards.

d. Interval between cards, twenty seconds.

It will be noted that by this method on each indicator card there were obtained twelve indicator diagrams; six for each end of the cylinder. The average mean effective pressure of these cards was taken to secure the indicated horse power for the cycle of three minutes above described. This three-minute cycle of 66% card indication, was practised several days until perfect runs were obtained between Woodlawn and New Haven, east and west. Then five continuous east and west runs were made for both express and express local service, and an average indicated horse power per ton for each class of service was obtained. By this method of continuous indication throughout all parts of the division, both east and west, the results would seem to be accurate.

5. *A Sufficient Number of days of Continuous Test to Secure Accurate Results.* Eighteen days were considered sufficient.

TABLE 3.

	Ton-miles per annum	Tons of coal steam traction	Tons of coal electric traction	Cost of coal steam traction	Cost of coal electric traction	Saving of electric over steam traction
Express. . .	592,240,000	57,447	29,870	$183,830	$89,620	$94,210
Express loc	348,000,000	58,300	28,600	186,560	85,800	100,760
Express frt	2,223,000,000	187,844	139,010	563,530	417,030	146,500
						$341,470

The test was conducted during the month of August. The track and temperature were favorable to steam locomotive traction.

Table 3 shows the relative amounts of coal required for electric *vs* steam locomotive traction. In the former case the coal as measured in the electric power house; in the latter as measured in the fire-boxes of the locomotives. The cost-item is interesting in this table, indicating that the New York Division when operated by electricity will show a saving by coal alone of $341,470.00 per annum.

It is to be noted that the pounds of coal per indicated horse power hour is not simply the weight of coal used to accomplish an individual engine run, but the weight used in an all-day service of 24 hours, which includes the time the engine is idle. As the engines are indicated for a given revenue run, this weight of coal might be well termed: The pounds of coal per revenue indicated horse power hour.

Eng. No.
FREI
300
301
306
325
373
382
383
386
448
453
PASS
832
841
1210
1258
1262
1271
1272
1282
1571
1574
FREI
300
301
306
325
373
382
383
386
448
453
PASS
832
841
121
125
126
1271
127
128
1571
157

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b. Locomotive Repairs. Table 4 is a typical sheet showing the scheme of accounts kept on each of the twenty locomotives for a period of one year. The sheets selected are those showing the maximum and minimum months for freight and passenger engines.

TABLE 5.

		Mileage made by locomotive	Total cost of repairs in $	Cost of repairs per mile in cents.	Total cost of maintenance in $	Total cost of maintenance per mile in $	Total cost of repairs and maintenance per mile in cents
FREIGHT	Aug. '06	22,342	1323.	5.92	292.	1.31	7.23
	July '06	22,843	1140.	4.99	257.	1.12	6.11
	June '06	26,570	920.	3.46	326.	1.23	4.69
	May '06	32,678	825.	2.52	451.	1.38	3.90
	Apr. '06	22,500	438.	1.95	367.	1.63	3.58
	Mar. '06	24,984	351.	1.40	335.	1.34	2.74
	Feb. '06	24,788	1254.	5.05	353.	1.42	6.47
	Jan. '06	29,848	5150.	17.26	433.	1.45	18.71
	Dec. '05	24,017	2961.	12.33	362.	1.51	13.84
	Nov. '05	29,528	2029.	6.87	455.	1.54	8.41
	Oct. '05	19,523	2050.	10.50	305.	1.56	12.06
	Sept. '05	19,825	1568.	7.91	320.	1.61	9.52
	Total...	299,446	20009.	80.16	4256.	17.10	97.26
	Average per mile...		6.68	6.68	1.42	1.42	8.10
PASSENGER	Aug. '06	32,409	2674.	8.25	638.	1.96	10.21
	July '06	32,199	373.	1.15	561.	1.74	2.89
	June '06	35,272	612.	1.74	583.	1.65	3.39
	May '06	34,833	5129.	14.70	674.	1.93	16.63
	Apr. '06	31,395	429.	1.37	554.	1.77	3.14
	Mar. '06	33,332	743.	2.23	575.	1.72	3.95
	Feb. '06	26,428	1040.	3.93	475.	1.76	5.69
	Jan. '06	37,008	385.	1.04	637.	1.72	2.76
	Dec. '05	31,977	830.	2.63	552.	1.73	4.36
	Nov. '05	43,485	1338.	3.08	681.	1.56	4.64
	Oct. '05	37,394	1172.	3.13	615.	1.65	4.78
	Sept. '05	41,304	1376.	3.33	621.	1.50	4.83
	Total...	417,036	16121.	46.58	7166.	20.69	67.27
	Average per mile...		3.88	3.88	1.72	1.72	5.60

Table 5 is a complete compilation of the twelve months of locomotive repairs and maintenance.

This investigation leads me to the two following conclusions:

1. For a mixed freight and passenger service the same gross draw-bar can be produced by the single-phase method of traction for 60% of the coal required by the steam method of traction.

2. Locomotive repairs are between three and four times as great for steam as for electric locomotives.

L. B. Stillwell and H. S. Putnam (by letter). The paper which we had the honor to present at the two hundred and thirteenth meeting of the American Institute of Electrical Engineers, as stated in its first paragraph, had four objects. 1, To record certain facts relative to heavy electric traction which had been established by experience; 2, to present calculations of relative costs of steam and electric traction in railway service based upon these facts; 3, to point out the transcendent importance of standardizing electric railway traction equipment as rapidly as may be consistent with progress; and 4, to raise the question whether a frequency of 25 cycles per second or 15-cycles per second should be adopted in railway operation by alternating-current motors.

Our purpose in working out and presenting detailed calculations of relative costs of operation by the steam locomotive and the single-phase motor was to secure for ourselves and others a comprehensive view of the great problem which railway engineers to-day are called upon to consider—a comprehensive view being obviously a requisite first step toward an adequate and satisfactory general solution. To realize the magnitude of the problem and the advantages in respect to increased earnings and decreased operating costs which in general will result from the substitution of the motor for the steam locomotive, is to recognize the fact that railways are destined to use electricity upon a scale which demands a general solution and to appreciate the importance of prompt standardization of the frequency chosen for alternating-current work.

While expressing the belief, that as compared with 25-cycles "a frequency of 15-cycles is preferable and should be adopted for heavy electric traction," we stated that our object was rather to present the question of frequency for discussion than to advocate the adoption of any particular frequency, and we suggested a careful consideration of this very important question by the Institute through its Standardization Committee or a special committee.

The oral discussion which followed the presentation of the paper was conclusive, beyond our expectation, as regards frequency. So far as the general practice of engineers who may adopt the single-phase alternating current is concerned, we regard the matter as practically settled by the facts and opinions brought out by the discussion. The designing engineers of both the Westinghouse and General Electric companies testified emphatically to the great increase in power of motors which can be realized by reducing the frequency, and while several speakers questioned the wisdom of now adopting a standard, no one came forward to argue that the higher frequency is preferable.

Mr. Lamme to whom, more than to any other man, we owe the single-phase motor, stated that at 15 cycles the output of a given motor is from 25% to 40% greater than at 25 cycles and that his company had verified this by actual test.

Mr. Storer testified that:

> You can get at least 30% greater output from motors with 15 cycles than with 25 cycles.

Mr. Slichter, the engineer of the General Electric Company, who has immediate charge of the work of designing single-phase motors, said:

> There seems to be a unanimous opinion that the output of the motor may be increased some 30 to 35% by a decrease in frequency from 25 to 15 cycles.

Mr. Potter, chief engineer of the railway department of the General Electric Company, after pointing out some of the difficulties in the way of the adoption of 15 cycles, said:

> I do not think, however, that we can look for the ultimate development of the single-phase motor of 25 cycles.

In his written contribution to the discussion of the paper, Mr. Frank J. Sprague says:

> It may be advisable in the end to adopt for alternating-current operation about this periodicity, and months ago I ventured to predict that the largest 25-cycle railroad enterprise now being installed would adopt a lower frequency.

Mr. Calvert Townley alone, among all who have orally or by written communication discussed the paper, advances arguments in favor of 25 cycles, but even in this case the position taken is one advocating suspension of judgment rather than asserting superiority of 25 cycles, as is shown in the following statement with which he concludes his letter:

> In the light of the foregoing the following seem to me clear:
>
> 1. That it would be wrong to establish a standard frequency for a single-phase railway operation at the same time.
>
> 2. That even after it has been credited with all the estimated advantages claimed for it, a 15-cycle frequency has not yet made out a case entitling it to general preference.

The paper and the discussion have established the fact that the increase in cost of the power-house equipment consequent upon the suggested reduction in frequency is far more than offset by the reduction in cost of electric equipment of rolling stock consequent upon the adoption of 15 cycles.

As regards power-house and sub-station cost, we estimated that the difference in favor of the higher frequency is about $10,000,000, assuming that all the American railroads now operated by steam should adopt electricity.

As regards cost of the electric locomotives, Mr. Storer stated that the difference in favor of the lower frequency would approximate **$5,000** per locomotive. In naming this figure, doubtless he had in mind the present cost of electric locomotives, while in our estimates we have assumed that this cost, which is now approximately **$30,000**, will be reduced to **$25,000**. Making a corresponding reduction in Mr. Storer's estimate, it appears that the saving per locomotive, in the opinion of the chief engineer of the railway department of the Westinghouse Electric & Manufacturing Company, will approximate **$4,000** in favor of the lower frequency.

The question whether 24,000 electric locomotives would do the work of approximately twice that number of steam locomotives now owned by the railroad companies is certainly open to discussion. If the actual number required be greater than the number assumed, the argument in favor of the lower frequency is strengthened. In our paper we expressed the opinion that work equivalent to that now done by approximately 48,000 steam locomotives could be performed by electric locomotives numbering from one-half to two-thirds of that figure, and in showing that the change to the lower frequency would effect a saving in first cost of aggregate equipment we used the smaller figure in order to be entirely fair to the higher frequency. Adhering to the figure, 24,000, as representing the aggregate of electric locomotives required, and taking Mr. Storer's figure of **$4,000** as representing the difference in cost per locomotive, it appears that while the adoption of the lower frequency would involve an increase of about **$10,000,000** in cost of power-house and sub-station equipment, it would save **$96,000,000** in cost of rolling stock equipment; both of these figures having reference to equipment of the entire existing railroad systems of the United States. The point made by Mr. Storer, therefore, greatly strengthens the argument in favor of the lower frequency.

The practical unanimity of competent opinion evidenced in respect to the advantages of the lower frequency, and the fact that practically every American designing engineer who has participated actively in the development of single-phase railway apparatus was present and joined in the oral discussion, would seem to have established definitely and finally the wisdom of adopting the lower frequency. It is possible that special cases may arise in which local conditions are sufficient in weight to justify the use of the higher frequency, but it is perfectly clear that hereafter the engineer who in single-phase alternating-current railway work adopts 25 cycles will accept serious responsibility and should be able to base his decisions upon concrete and local factors such as will be found to exist in very few cases.

The fact that the Oerlikon Company, of Switzerland, and the Siemens-Schuckert Company, of Germany, in manufacturing single-phase motors of the type adopted by the Westinghouse and General Electric companies are adopting **15** cycles, is an interesting point presented by Mr. Lamme and is excellent evidence in favor of the lower frequency.

Aside from the interesting discussion of the question of frequency, the paper has resulted in the presentation of certain facts of material value and of numerous opinions, many of which deserve respectful consideration. Among the facts of special value may be mentioned the data presented by Messrs. Lamme and Potter relative to comparative slip of wheels at 15 and 25 cycles. It is highly desirable, however, that these facts be supplemented by further experimental determinations. Mr. W. S. Murray has contributed data of especial value in the shape of costs of steam locomotive operation on the New York, New Haven and Hartford Railroad, these costs being in certain respects analyzed more thoroughly than is usual in the locomotive performance records of our steam railroads. Mr. Slichter's figures showing how the cost of electric equipment in certain cases would be affected by the suggested change in frequency, are of particular interest. Mr. de Muralt's discussion of certain comparative characteristics of single-phase, three-phase and direct-current motors is also of value. It is to be regretted that the comparative merits of the two frequencies under consideration were not discussed from the standpoint of the induction motor. The point was referred to in our paper, and Mr. Ralph D. Mershon in his printed communication expresses the opinion that in the near future this consideration will have greater weight than is now generally recognized. It is certainly desirable to have additional light upon this aspect of the subject, and it is to be hoped that if the advocates of the induction motor for traction purposes have in their possession any facts of importance not yet published they will see their way to present such facts at an early date.

Aside from the discussion of the question of frequency and the presentation of test data, the oral discussion and the written communications subsequently contributed bring out the following factors:

1. That Mr. Frank J. Sprague, and possibly a few other engineers, are inclined to believe that the high-potential direct-current motor, (for example, 1200 or 1500 volts) is perferable to the singlé-phase motor.

2. That a considerable number of engineers feel that the time to standardize has not yet arrived.

Such advantages as the direct-current motor possesses in the general railway field disappear rapidly when we consider this field as a whole rather than regard special cases in which the reasons for electrification are so weighty as to overcome even the comparative disadvantages of a system apparently limited to 1200 or 1500 volts, and necessarily limited by the interposition of synchronous converters between generators and motors no matter what the ultimate voltage for which direct-current motors may be designed. They also shrink materially when we compare the direct-current motor with the 15-cycle motor instead of the 25-cycle motor.

In the course of the discussion, Mr. Sprague made the following interesting statement:

> I am going to make a prophecy—that on a large number of lines which can by any stretch of imagination be considered as subject to a reasonable prospect of electrification that 1200 or 1500 volts will on any present development known give better results in every way than the alternating-current 15- or 25-cycle overhead system.

It is to be hoped that Mr. Sprague will present facts and figures upon which this interesting prophecy is based. Meantime, however, it may be pointed out that he limits the alleged superiority of the direct-current system to:

> A large number of the lines which can, by any stretch of imagination, be considered as subject to a reasonable prospect of electrification.

The imagination of one man may stretch more than that of another, and in effect Mr. Sprague proposes the plan of special solution. The growth of traffic will constantly operate to bring roads now outside what he considers the practicable field, within that field. Obviously, it will not do to treat this problem as limited to roads having to-day certain density of traffic or limitations of length which may enable the direct-current system to make a good showing. Problems which ten years ago were on the remote horizon are solved and behind us, while problems which twenty years ago were regarded only by the poet are now in the hands of the operating superintendent.

The position which we take in this matter may be stated as follows:

a. A general view of the railway field, including freight as well as passenger traffic, obviously shows that for anything approximating a general solution the single-phase alternating-current system is decidedly superior to the 1200- or 1500-volt direct-current system. This conclusion is corroborated by calculations easily made and based only upon established facts.

b. The admitted advantages of electricity in respect to increased earning power and decreased cost of operation are such as in the near future to assure rapid increase in the use of electricity by railway systems now operated by steam.

c. The necessity of standardizing frequency rests practically, although less directly, upon the same arguments as have induced railways to standardize track-gauge, height of draw-bar, location and couplings of air brake, train-line, and steam-line.

In other words, the significance of our estimates of comparative operating costs is that the results, viewed in connection with admitted facts in respect to increased earnings, indicate that a general electrification of important railway divisions, and even of trunk lines, is coming much more rapidly than has been realized, even by electrical engineers; and the lesson to be drawn from this conclusion is that we must standardize as promptly as possible everything essential to convenient interchange of rolling stock.

As regards multiple-unit control equipment, to which Mr. Sprague refers, it will be absolutely necessary to standardize this, at least so far as the train-line connection is concerned, if the time should arrive when freight trains are to be operated by electric locomotives located at intervals throughout the train. Undoubtedly this possibility now appears remote, by reason of the fact that it would call for a general equipment of the freight cars used by all railways in the United States. It is precisely by this method, however, that the greatest possible advantages of electrification might be obtained. The enormous gain resulting from the ability to operate freight trains of any desired length without increasing the strain on draft-gear, and by a system permitting instant and effective train control at the will of the motorman on the leading locomotive, is obvious to every railway engineer or operator; and it is probable that in no other way could the ability of some of our trunk lines to handle the freight traffic which to-day is overcrowding their existing track facilities be more economically increased. Not many years ago railway operators, in general, regarded the proposition that freight cars be supplied with air-brake equipment as an impracticable dream; to-day the supposed dream is a reality in respect to more than 85 per cent. of this class of rolling-stock equipment. Similarly the idea of equipping all cars with automatic couplers was opposed as impracticable, but to-day such couplers are in general use. In view of these facts, and of the enormously valuable results which might be attained in the case of many trunk lines by employing the multiple-unit system, we contend that the argument in favor of the selection of a standard system of electric supply for railway operation is materially reinforced by the possibility that multiple-unit control may be used in the not very distant future in the operation of freight trains.

It is suprising to find Mr. Armstrong and a few other engineers opposing the idea of standardizing ordinary railway practice. The explanation of their attitude must be found either in the fact that they have inferred more than was intended by our use of the word "standardization," or that they have failed to realize an adequate general view of the railway problem which confronts electrical engineers.

Our paper proposed that standards of practice be agreed upon in respect to: *a*, location of third rail; *b*, location of overhead conductor used with single-phase alternating-current systems; *c*, frequency of alternating traction systems. We remark also that it is clearly desirable but probably less easy to agree upon a standard system of multiple-unit control for train operation.

As reported in the stenographic notes of the discussion, Mr. Armstrong said:

> It is not a case of types of apparatus, or a question of frequency. Each case has to be considered by itself. In ten years from now we will still be disputing over the question of frequency, alternating-current or

direct-current operation. Looking back on the history of the steam locomotive, we have no standard. You can talk to the representatives of the different roads, the master mechanics and different engineers, and they have their own ideas about various matters in connection with their locomotives, * * *

Undoubtedly ten years from now the master mechanics and engineers of electrically operated railroads will still have their own ideas about various matters in connection with their locomotives. As regards all things essential to interchange of rolling stock, however, it is safe to assume that practice will be uniform; and the earlier uniformity is attained, provided that system best fitted to survive is selected, the better for all concerned.

The question whether it be wise or unwise now to agree to set aside as inadequate for the solution of the general railroad problem all direct-current systems, depends upon the question whether we now possess adequate knowledge of the possibilities and limitations of the contrasted systems. It is our contention that such knowledge is now available.

In 1890 the standard frequency of 60 cycles was chosen for lighting purposes. This choice was based upon knowledge certainly not more complete in respect to the requirements of the field of use, and the limitations and possibilities of apparatus applicable thereto, than is now available to enable us to make a wise choice of frequency for railway apparatus. In 1890, 60 cycles was not a case of the survival of the fittest. As a matter of fact, when it was chosen as the standard frequency to supersede the higher frequencies previously in use, it had never been embodied in a commercial plant in actual operation. Nevertheless it appears to have withstood successfully the test of time.

Similarly in 1890 the Westinghouse company selected as standard for work in which synchronous converters were to be employed extensively, the frequency for 30-cycles. About two years later, and before any important plants using 30-cycles had been installed, this was changed to 25-cycles, owing primarily to the fact that the Niagara Falls Power Company had arranged to install turbines operating at 250 rev. per min.—a speed which did not permit the development of 30-cycle current by alternators directly connected to the turbine shafts.

The frequency, 25 cycles, when adopted for the Niagara installation, was not selected as the survival of the fittest among a number of alternative frequencies preferred by various engineers and experimented with in commercial service at the expense of the purchaser. At the time it was chosen, knowledge of the facts essential to a wise choice was far less exact and comprehensive than to-day is our knowledge of the considerations which should enable us to predetermine and select that frequency which is best fitted to survive in railway service.

In his exceptionally valuable contribution to the discussion, Mr. H. M. Brinckerhoff takes the position that the essential condition of interchangeability of through equipment does not prevent the selection, locally, of a variety of motive power systems:

Provided the present degree of standardization common in steam railway practice is adhered to.

The question is very important, and it is a fortunate fact that electric rolling-stock equipment offers many interesting possibilities of operation over lines supplied with electric motive power of various types. Such operation, however, as illustrated by the equipment of the New York, New Haven and Hartford Railroad, which is adapted not only to the 11,000-volt single-phase overhead system chosen by that company, but also to the direct-current third-rail system of supply used in the Forty-second Street terminal, implies, necessarily, a degree of complication expensive, and, from the operating standpoint, very undesirable.

If some of our railways are to use 6,600-volt overhead trolley systems of supply, others 11,000-volt systems, still others 1,500-volt direct-current systems, 600-volt third-rail systems, and any other systems which ingenuity can suggest, no conceivable complication of rolling stock equipment will permit operation of motive-power units over the railway lines of the country as a whole.

As regards the necessity of standardization in order to avoid confusion and loss as the zones of electrification of our railway systems are extended, the following considerations, not specifically mentioned in the paper or in the discussion, and apparently overlooked by some who have discussed our paper, may be referred to:

1. The effect of consolidations. The doctrine of special treatment of individual cases of electrification now presented to the electrical engineer, if adopted, will lead to needless expense and great inconvenience in operation in cases where properties equipped with different systems may be consolidated at some future date. The same is true in case of a transfer or sale of a section of line by one railroad property to another.

2. In emergency, in case of accidents blocking the line, our steam railways not infrequently send their trains to destinations by using lines belonging to neighboring railways under different management. If one line is to use the 1200-volt direct-current system, and another the alternating-current system, such accommodation will be impossible.

3. At junction points and terminals the use of different systems in permitting interchange of rolling stock is in many cases practically prohibitive. Every terminal in the city of Chicago is in use by two or more trunk-line railways, and in such a case as this obviously uniformity of systems, frequency, etc., is essential.

It appears unnecessary to elucidate further the reasons which from an operating standpoint argue so strongly against the idea of special solutions of individual cases. Every experienced railway man will recognize their force without argument.

It has been suggested that the adoption of a standard system of supply for railway lines may retard progress by limiting, or checking, the spirit of emulation and competition of inventors and engineers. This question, it will be noted, is not raised by our suggestion that the frequency, 15-cycles, be adopted as a standard for alternating-current railway work. Obviously the opportunities for improvement and development are quite as great at 15 cycles as they would be at 25 cycles.

The question is pertinently raised by our expressed opinion. that for a general solution of the broad problem of railway electrification only alternating-current systems are deserving of serious consideration, and those who believe that direct-current systems may be capable of development to a point which will make them, or one of them, effective and satisfactory for the solution of the general problem, are justified in making the point referred to. For ourselves, the arguments in favor of the alternating-current system are such as justified the setting aside of direct-current systems and concentration of effort in the prompt standardization and more rapid development of the alternating-current system, which, by its essential characteristics, is obviously best adapted to the solution of the general problem.

It is pointed out that the existence of a certain number of 25-cycle generating plants, sometimes owned by the railway, and possibly available as a source of power supply for emergencies, is a consideration of weight in some instances. The answer to this is that undoubtedly in each specific case of contemplated electric installation the problem should be carefully studied with reference to local as well as to more general considerations, and it is not impossible that in some cases the weight of local considerations may justify departure from the general standard. This obvious fact, however, does not argue against the general adoption of a standard. So far as it has weight, undoubtedly it argues in favor of 25 cycles, but it in no way supports the position, which some have taken in opposition to our contention, that a standard should be promptly agreed upon.

One or two contributers to the discussion have criticised our use of the *Statistics of Railways*, issued by the Interstate Commerce Commission, on the ground that these reports are not reliable. For our purposes and as used by us they are, on the contrary, entirely adequate and convincing. The fact that they are not complete in detail does not materially affect their value for our purposes, as we are dealing with the ratio of the individual items to the total operating expense. Obviously, the ratio of saving indicated by our calculations cannnot be applied to individual roads indiscriminately. It could be so applied only to a railway which might happen to represent exact average conditions. It is hardly necessary to explain that the management of any railroad contemplating the adoption of electricity must study the problem with reference to its detailed and carefully analyzed conditions and costs of operation. In attempting to fix comparative costs of the various items of operating expenses, moreover, we have used not only the reports of the Interstate Commerce Commission, but the annual published reports of many railroads and also detailed unpublished reports kindly furnished by officials of the Pennsylvania, the Erie, Missouri Pacific, Denver and Rio Grande, and other railroad companies.

One or two critics have considered it unfortunate that, in connection with our calculations of comparative operating costs, we did not include an estimate of the capital charges involved in the case of electric equipment. This omission was deliberate. To include capital charges is in no way essential to the purposes of our paper, and to do so would raise questions tending to divert attention from the object which we had in view. For example, the treatment of the question of " depreciation " is one which might well become the subject of a paper of considerable length, and the methods of financing railroads in America are so far from having attained a standard of practice that we have deemed it best to show only the calculated saving in operating costs per mile of line as compared with interest on the cost of required electric equipment, exclusive of rolling stock.

Several gentlemen who discussed the paper expressed the opinion that, while the apparent reduction in operating costs, as shown by our analysis, is 18% (exclusive, of course, of capital charges), roads in general will not make the change in order to effect this economy, but will be influenced to a much greater extent by the increased earning power resulting from the change. This consideration is not new to the authors. One of them recalls pointing it out to the president of the Manhattan Railway Company some ten years ago.

The results of our estimates, in which we have endeavored to compare the operating expenses under a system of electric traction with the actual grand averages of operating expenses throughout the United States, are more favorable to electric traction than we had anticipated when this work was undertaken, but it is hardly necessary to point out that no competent engineer would infer from these results that every railway in the United States is likely to be electrified in the immediate future. The possible economies effected by such substitution, however, when considered in connection with the increase in earning power to be anticipated, leads to the conclusion that the electrification of our railways is destined to be carried on much more rapidly than is realized to-day by the average engineer, and emphasizes the necessity of prompt standardization of everything essential to convenient exchange of rolling stock.

The communication from Mr. A. H. Babcock is interesting, but has no particular bearing on the general railway problem under consideration. He objects to our expressed opinion that alternating-current equipment is the only class of equipment deserving serious consideration in connection with the general problem of heavy traction. He has found an alternating-current installation comprising three passenger cars and two work cars weighing about 40 tons each. These cars are operated by 25-cycle single-phase current obtained from a 60-cycle source through the interposition of a motor-generator set. The energy is metered and paid for on the three-phase side of this set. The conditions of service are in no way defined, but the limited equipment suggests a very low load-factor and consequently very low efficiency of conversion from 60 cycles to 25 cycles.

Mr. Babcock asserts that if the 1200-volt direct-current system were used the energy per ton-mile would be 30% less. This is easily conceivable, particularly if Mr. Babcock has based his calculations upon the use of synchronous converters in this case as against a motor-generator set as in the other. The case to which he refers is obviously one of ordinary interurban trolley operation, with frequent stops; and in this field many cases of direct-current practice might be adduced in which the energy consumed per ton-mile, owing to special and local conditions, is comparable to that which he has found in this particular instance of alternating current. Obviously, the point which he attempts to make is not one which will materially influence general conclusions in respect to the problem of heavy traction. Mr. Babcock asserts his intention:

> To reserve the right to choose for every specific case the type of apparatus best adapted.

In the interest of the great railway property for which he is retained as electrical engineer, it is to be hoped that he will bestow further consideration upon this very important question of engineering policy. The 1200-volt direct-current system is probably capable of attaining excellent results in a limited field, such as the electrification of a terminal, but generally speaking the system adopted for the electrification of a terminal should be one adapted to future extension to the railway division or even to the trunk line.

The substantial accuracy of the general results of our calculations relative to reduction of operating expense resulting from the substitution of the electric motor for the steam locomotive has not been seriously questioned. Our estimates of the aggregate output and cost of power-house equipment which would be required for the operation of the entire system of the United States rest primarily upon certain stated assumptions as to length of line supply from a given power house, and to this fact some reference has been made in the discussion.

We therefore avail ourselves of the opportunity to supply, in the form of an appendix to our paper, an explanation of methods used in determining power-house output and load-factor, a statement relative to the effect of resistance due to grades, and also a brief statement relative to recuperation.

Clarence Renshaw (by letter): Mr. A. H. Babcock has contributed to the discussion of the Stillwell-Putnam paper by letter. He describes his observations on a visit to a single-phase electric railway. I have been intimately conversant with the operation of this railway through engineering reports from those who have had charge of the installation and initial operation of the apparatus.

Mr. Babcock has neglected to mention a number of facts which materially affect the conclusions which should be drawn from the material which he does give. To overcome certain specific faults in insulation and workmanship, which developed in operation, the motor armatures were rewound. A number of the men whom Mr. Babcock mentions were presumably engaged upon this work, as the normal number which is now employed is very much less.

During the month to which it is presumed Mr. Babcock refers, the total car-mileage of the road was 15,797 miles, including trailers and freight cars. The total motor-car mileage was only 13,009 miles, or approximately 87 miles per car per day. The cars were operated at a schedule of approximately 19.5 miles per hour between terminals, so that the daily mileage of a car represents only about 4.5 hours actual running. Under such circumstances, the load-factor in necessarily very low and the power consumption, on a car-mileage basis, from the 60-cycle circuit, where the power measurements referred to by Mr. Babcock were taken, is necessarily high. This was further accentuated by the fact that, at the time of his visit, polyphase generators which were not well adapted for this service were used for supplying single-phase current. These have since been modified by rewinding them for single-phase operation. Since this modification, one generating set is ordinarily ample for operating the road, whereas two motor-generator sets in parallel were usually required during the month to which Mr. Babcock refers. Consequently, the conversion losses in the sub-station were abnormally high.

Even the figures which are given—153 watt-hours per ton-mile—are not unusual when the load-factor is low. I have a test giving the actual measurements on a road through synchronous converter sub-stations. Three cars of 28 tons operating on this road required 202 watt-hours per ton-mile during the month of January, 1906. This illustrates the high power requirements per ton-mile when there are but few cars and the load-factor is low. A comparison of these two examples shows the marked advantage of single-phase operation under such conditions.

It may be noted that the company operating the road to which Mr. Babcock refers has given a favorable judgment on the operation of the road, as indicated by considerable extension and an increase of more than 100 per cent. in their car equipment.

ERRATA.

Page 291, 13th and 14th lines from bottom, should read: " 1. That it would be wrong to establish a standard frequency for single-phase railway operation at the present time."

Page 293, 16th line from bottom, for " factors " read " facts."

Page 294, 15th line from bottom, for " future to assure," read " future assure."

Page 298, 17th line from top, for " such as justified," read " such as justify."

A paper presented at the 217th meeting of the American Institute of Electrical Engineers, New York, March 29, 1907.

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(*Subject to final revision for the Transactions.*)

LIGHTNING PHENOMENA IN ELECTRIC CIRCUITS.

BY CHARLES P. STEINMETZ.

1. Originally lightning denoted electric discharges between clouds or between cloud and ground, and, when applied to an electric circuit, the results of such a discharge striking the line. Later it was found that during atmospheric disturbances, such as passing thunder storms, disturbances occurred in electric circuits even without the discharges striking the line. These disturbances—caused by induction—were also classed as "lightning," and applied to electric circuits, lightning then came to mean all the effects of atmospheric electricity.

With the introduction of electric circuits of higher voltage and larger electrostatic capacity, phenomena were observed in such circuits of the same character and effect, and requiring the same protective devices, as the disturbances caused by atmospheric electricity, even in cases where atmospheric effects were excluded, as in underground cable systems. The term lightning when applied to electric circuits, therefore, was extended to cover also these effects, which are due to internal circuit changes, as changes of load, discharges through weak places of the insulation, etc.

The damage done by lightning to telegraph and telephone circuits being relatively small compared with the disastrous effects occasionally occurring in high-potential systems of large power, it was acknowledged that frequently most of the damage is done by the power generated in the system; the atmospheric or other disturbance merely started the phenomenon. The term lightning was thus once more extended to include all the abnormal phenomena of the flow of generated power of the system, which result from an atmospheric or other disturbance.

In its most general meaning, as understood now when dealing with electric circuits and their protection, *lightning denotes all phenomena of abnormal voltage and abnormal frequency.*

The lightning phenomena in electric circuits then comprise:

External lightning, the disturbances due to atmospheric electricity.

Internal lightning, the disturbances due to defects of the circuit or its operation, etc., and

Surges, that is, disturbances in the flow of generated power, brought about by the external or internal lightning and depending for their energy on the power of the generator system, hence frequently destructive.

2. The phenomena of abnormal voltage and frequency in electric circuits are the same three classes of phenomena met with in the disturbances in any medium which is the seat of energy:

1. Steady stress or gradual electric charge.
2. Impulse or traveling wave.
3. Standing wave or oscillation and surge.

1. *Electric Charge.* The potential difference against ground, or pressure of the total electric circuit, may gradually rise by an electric charge accumulating in the circuit—just as in a body of water, a river, the height may gradually rise until the water breaks through the embankment—the electric charge discharges across the lightning-arresters, or punctures the insulation, whichever is the point of least resistance.

Some causes of such steady and gradual accumulation of electric charge, and of potential difference against ground, of an electric circuit, are:

a. Collection of static charge from rain, or snow-drift, or from fog, carried by the wind across the line. Illustrating this on a three-phase system with insulated neutral, it will be seen that the potential difference against ground, which normally is symmetrical, Fig. 1, Curve I, gradually, by the simultaneous static charge of all three lines, changes to Curves II, III and IV, until the maximum potential difference against ground is sufficient to discharge to ground. The system then returns to the condition Curve I, and then traverses the same cycle again. This electrostatic accumulation of charge, in the case of efficient lightning protection, may appear as a series of discharges over the lightning arresters, which periodically follow each other.

b. Electrostatic induction from a passing cloud.

Assuming, for instance, a positively charged cloud passing over a transmission line. The ground below the line then carries a negative electrostatic charge, corresponding to the positive charge of the cloud. The line should have a negative charge

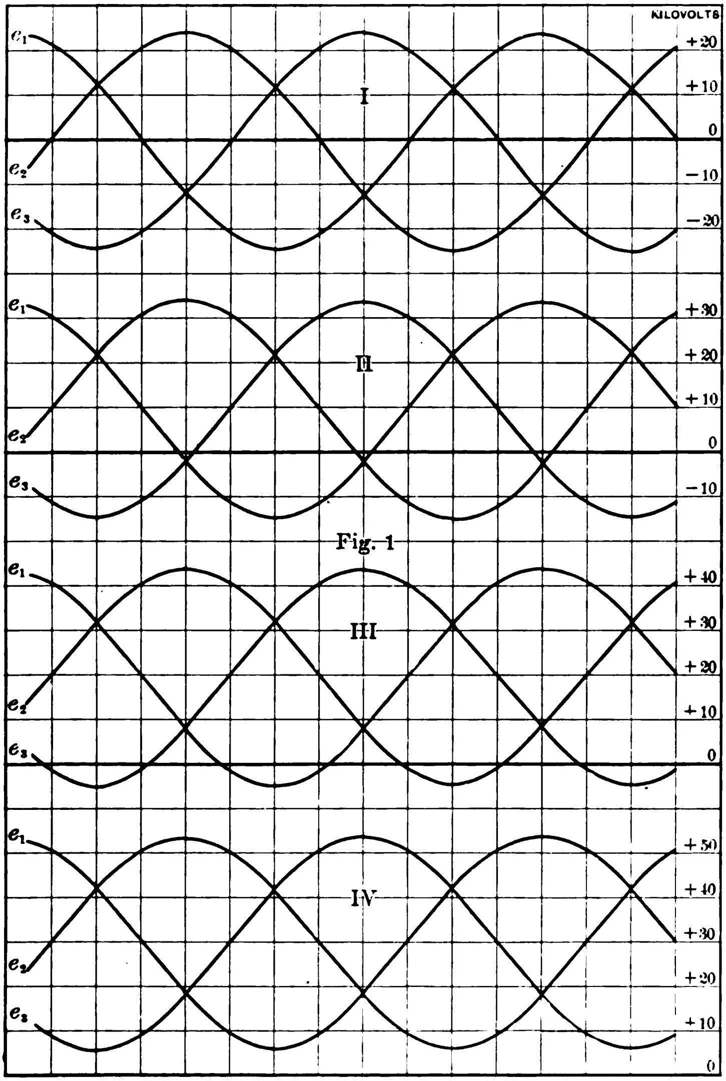

Fig. 1

also, even higher than the ground, since projecting above it. If the line is insulated from the ground, without the negative charge required for electrostatic equilibrium, it thus appears at a positive potential against ground; that is, at cloud potential. With the approach of a positively charged thunder cloud to the transmission line, the positive potential of the line against ground rises until a discharge takes place from the ground to the line, charging the line negatively. Inversely, with the cloud receding from the line, the line remains negatively charged: this charge not being bound any more by the positive charge of the cloud, discharges to ground. That is, during the approach and during the recession of a thunder cloud, discharges may occur between a transmission line and the ground, in the former case with the line of the same potential, in the latter case, with the line of opposite potential to ground, as the cloud, and due to a gradual accumulation of electrostatic potential difference, by induction from the cloud.

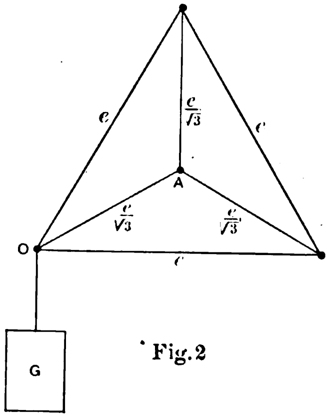

Fig. 2

This is the same phenomenon as, in the electrophorus of the physical laboratory, an equal charge appears on the inductor when approaching it to the resin plate; an opposite charge, when withdrawing it.

c. Potential differences between line and ground due to differences of atmospheric potential in different regions traversed by the line, especially if the line passes through different altitudes, as valleys and mountain ranges.

d. Accidental electrostatic charges entering the circuit, as friction electricity from the belt of belt-driven machines.

Somewhat similar phenomena result from:

e. Unsymmetrical conditions of the generator potential. For instance, if in a three-phase system one line is grounded, with the three-phase voltage e between the lines (Fig. 3) and $\frac{e}{\sqrt{3}}$ between lines and neutral, the mean potential of the total system is that of the neutral point A, hence, with a ground G at O, the total system as a whole has an alternating potential difference $OA = \frac{e}{\sqrt{3}}$ against ground, and induces electrostatically or causes other disturbances, with this potential difference.

f. Existence of higher harmonics in the electromotive force wave of a polyphase system, of such order that they coincide in the different phases; that is, the whole system rises and falls with their frequency. So in a three-phase system, the 3d, 9th, 15th, etc., harmonics coincide and may cause trouble, where they appear, as for instance, by star connection or primaries and secondaries of transformers with grounded neutral.*

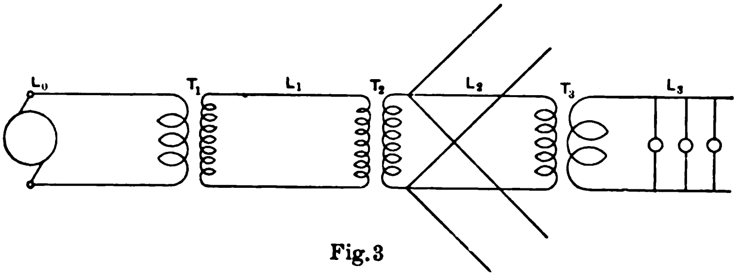

Fig. 3

The danger of such accumulations of potential lies:

a. In their liability to damage the insulation of the system by puncture, and

b. In their liability of producing, by their discharge, other and more serious disturbances.

In taking care of them by lightning-arresters arranged to discharge at a safe margin of voltage above the normal, the main problem is to arrange the discharge path so that the discharge passes harmlessly; that is, without producing other disturbances. It is the same problem as in the protection of a water-power station against freshets by dam and overflow, safely to discharge the water by means of the overflow.

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*See A. I. E. E. Proceedings, November, 1906, Discussion.

3. The effects of steady electrostatic stress, whether unidirectional, *a* to *d*, or alternating as *e* and *f*, appear not only in its own circuit, but also in circuits in inductive relation thereto, and may even be more serious in secondary circuits. For instance, let Fig. 3 diagrammatically represent a transmission system, comprising generating station L_0, step-up transformers T_1, transmission line L_1, step-down transformers T_2, primary distribution circuits L_2, a local lighting transformer T_3, and house light circuit L_3.

All these circuits have capacity against ground, and the transformers also capacity between primary and secondary, and as regards the electrostatic capacity, the system can diagrammatically be represented by Fig. 4.

Let C_0, C_1, C_2, C_3, represent the capacities against ground respectively of the generating station L_0 and the circuits L_1, L_2, L_3 (including the capacities of the corresponding transformer coils against ground) and, C_1', C_2', C_3', the capacities between primary and secondary of the transformers T_1, T_2, T_3.

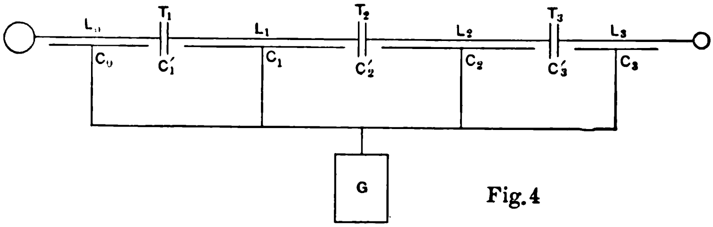

Fig. 4

An electrostatic charge of line L_1, giving the potential difference against ground e_1, also has an electrostatic path to ground, over the two capacities C_1', and C_0 in series, and so produces a potential difference against ground, e_0, in the generator circuit L_0, which is intermediate between e_1 and 0, in the proportion of the capacities C_1' and C_0; that is,

$$e_0 = \frac{C_1'}{C_1' + C_0} \tag{1}$$

e_0 is very much lower than e_1, but the circuit L_0 is of very much lower voltage than the circuit L_1, and while e_1 may be a safe voltage for the high-potential insulation of L_1, the lower voltage

e_0 may be beyond the safe limit of the insulation of the low-potential circuit L_0.

If L_0 is a generating station, or sub-station, its capacity against ground, C_0, is so large compared with the capacity C_1', that for steady stress the voltage e_0 is generally negligible, and this phenomenon is appreciable only when e_1 is an alternating potential, or the high frequency of an impulse or oscillation. Hence, this phenomenon is of importance only where the capacity of the low potential circuit against ground is small. This may be the case in a house lighting circuit. An electrostatic, or alternating voltage (case *e* and *f*) e_2 in the primary distribution L_2, gives an induced voltage:

$$e_3 = \frac{C_3'}{C_3' + C_3} \tag{2}$$

in the circuit L_3, and with the short extent and so low capacity C_3 of a local house lighting circuit, and a voltage e_2 of several thousand volts, e_3 may be sufficient to involve under unfavorable conditions at least a fire risk. The voltage e_3 is reduced by reducing the effective capacity C_3' by grounding the transformer core and case of T_3, but entirely eliminated only by grounding the circuit C_3.

2. *Impulse and Traveling Wave.*

4. The second class of phenomena is the impulse or traveling wave. A sudden local electrostatic charge of a transmission line, as by a lightning stroke, or inductively by a lightning flash suddenly discharging a cloud, or any other sudden local change produces a wave of potential and of current which runs along the line, just as a water wave over the ocean surface.

Such a potential wave or impulse is very high and of steep wave front at its starting point or point of impact, but gradually broadens and flattens out, and ultimately disappears, if the line is of unlimited length, just as the wave produced, for instance, by throwing a stone into a body of water is steepest at the point of impact and gradually flattens out and disappears. Successive stages of such a traveling electric wave are illustrated by Figs. 5 and 6.

Such a wave, when reaching the end of the line, is reflected and thrown back, thus returning again and so forming a system of nodes, and maxima, as shown diagrammatically in Figs. 7 and 8; that is, a standing wave.

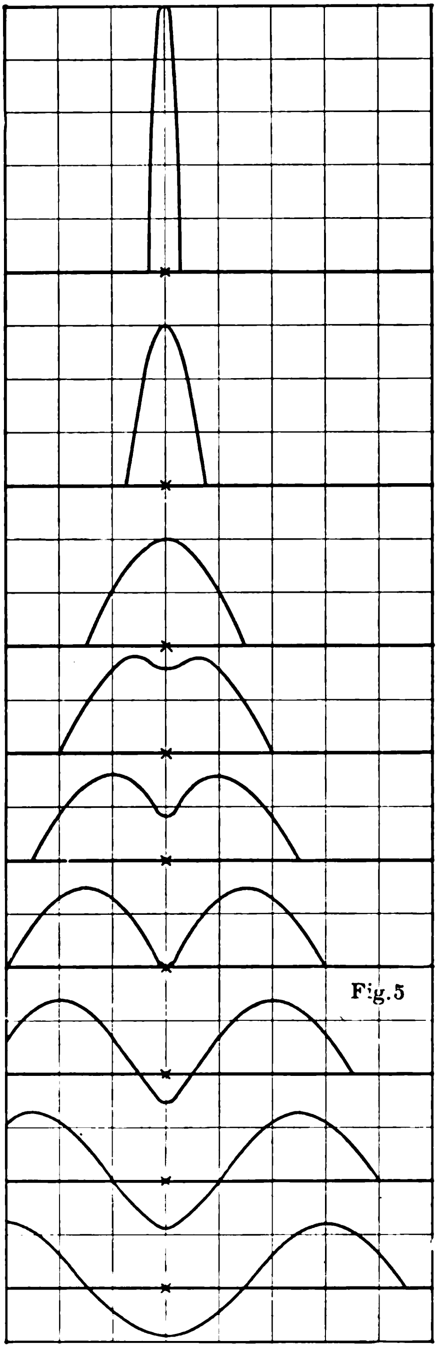

Fig. 5

When reaching the station—generating or sub-station—such a traveling wave is partly reflected by inductance of reactive coils, transformers, instruments, etc., partly transmitted. The different reflected and transmitted waves so superpose upon each other; that is, the impulse is broken up into a number of secondary impulses and local standing waves, which may reach voltages far higher than that of the traveling wave, just as an ocean wave when approaching the beach is broken up into the

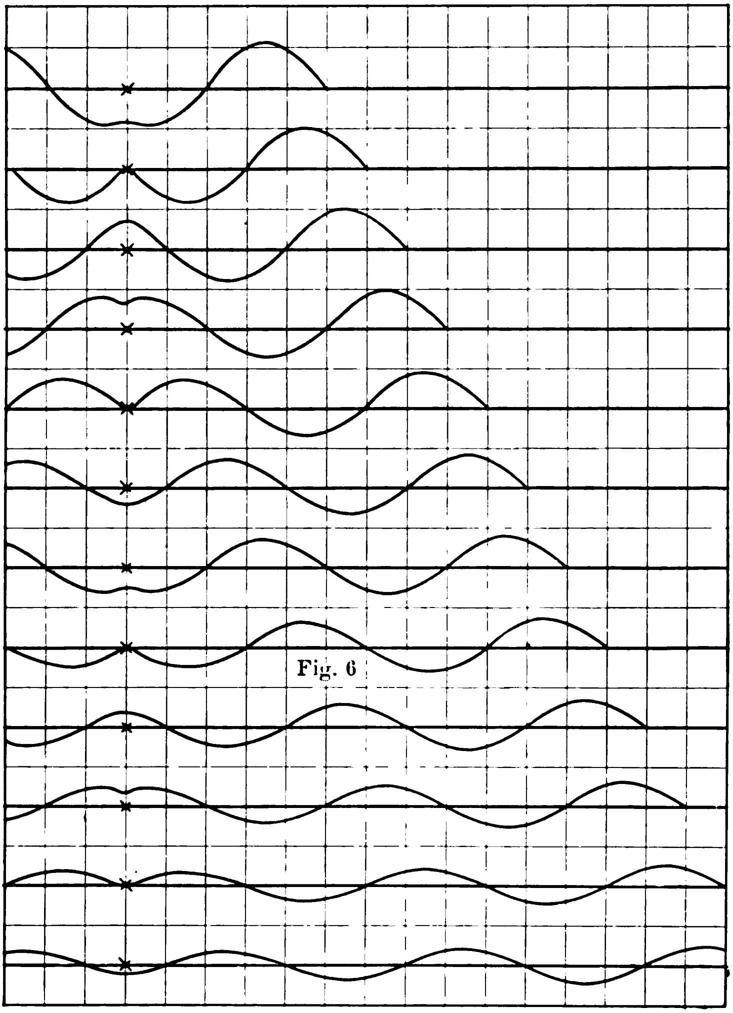

Fig. 6

surf, with wave-crests far exceeding in height that of the unbroken wave.

The complex system of phenomena resulting from the approach of a traveling wave to a station is analogous to the breaking up of an ocean wave into surf, and may indeed be called "electrical surf." While individual effects, as the formation of high-frequency standing waves or oscillations from an electro-

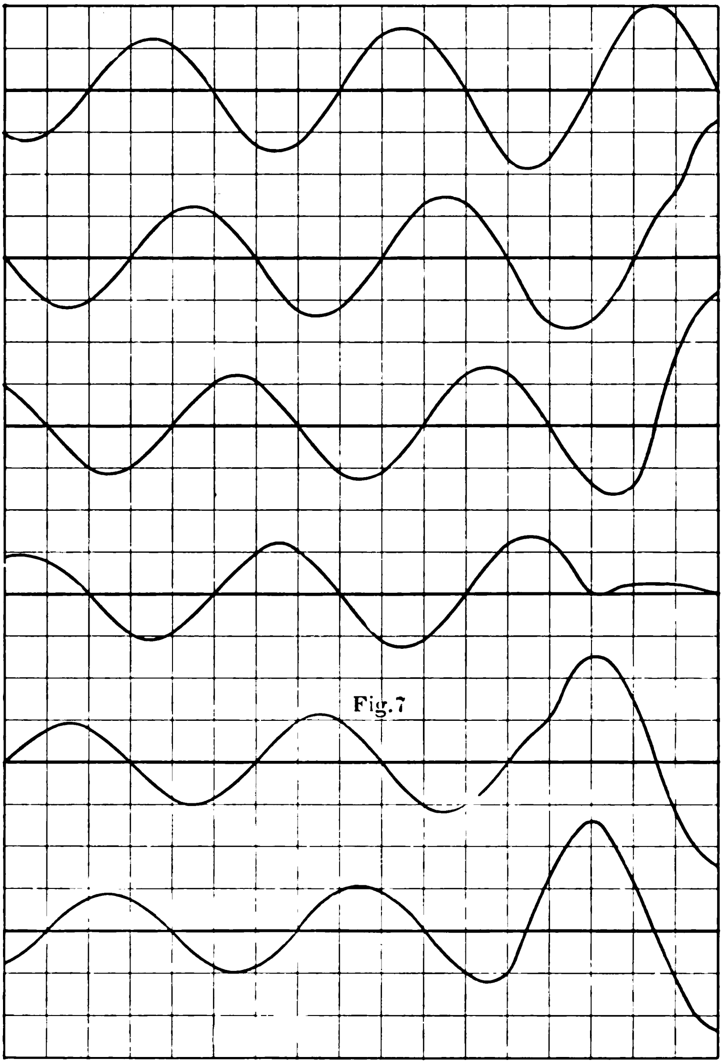
Fig. 7

static impulse entering a circuit of inductance and capacity, the effect of an inductance in the path of an impulse, the phenomena occurring at a branching point between two circuits, etc., can be calculated, the complete predetermination of all the electrostatic and electromagnetic effects of an electric wave entering the complex system of circuits of a station is no more feasible than the exact calculation of the motion of the water particles of an ocean wave when it breaks as surf at the beach.

The breaking up of an impulse or a series of impulses or traveling waves, in entering a station, appears as electrostatic displays, sparks, streamers and brush discharges, at conductors switchboards, etc., the so-called " static," which signals in the station the existence of a disturbance on the line.

The general equations of a traveling wave are of the form:

$$\left.\begin{aligned} e &= \sum_{1}^{\infty}{}_k\ \varepsilon^{a_k u - b_k t} A_k \cos(k c u - w_k) \cos(k g t - \phi_k) \\ i &= \sum_{1}^{\infty}{}_k\ \varepsilon^{a_k u - b_k t} B_k \cos(k c u \cdot w_k') \cos(k g t - \phi_k') \end{aligned}\right\} \qquad 3$$

5. Some of the causes of such traveling waves are:

a. Direct or secondary lightning strokes entering the transmission line. This usually gives a single impulse, or very few impulses of extreme steepness of wave front, but short extent, and capable of exerting very considerable power only locally, but not after traveling considerable distance; that is, a direct lightning stroke may shatter several poles, but do no damage to the station, if not very near to it.

b. Electrostatic induction by the clouds. Corresponding to the electrostatic potential between cloud and ground an electrostatic charge exists on the line. Every lightning flash in the cloud, and between cloud and ground, represents an abrupt change of the electrostatic potential and requires a rearrangement of the electrostatic charge on the section of the line below the cloud, and thus gives an impulse of an intensity corresponding to the intensity of the flash, or rather the magnitude of the change of electrostatic potential of the terrestrial field. Thus during a thunder storm, or other atmospheric electric disturbances near a transmission line, a series of impulses travel along the line, increasing in severity and frequency with the approach, and decreasing again with the recession of the storm. While each of these impulses is rarely of sufficent power to do serious damage, due to their frequency of recurrence, they may ltd eao the production of destructive internal surges.

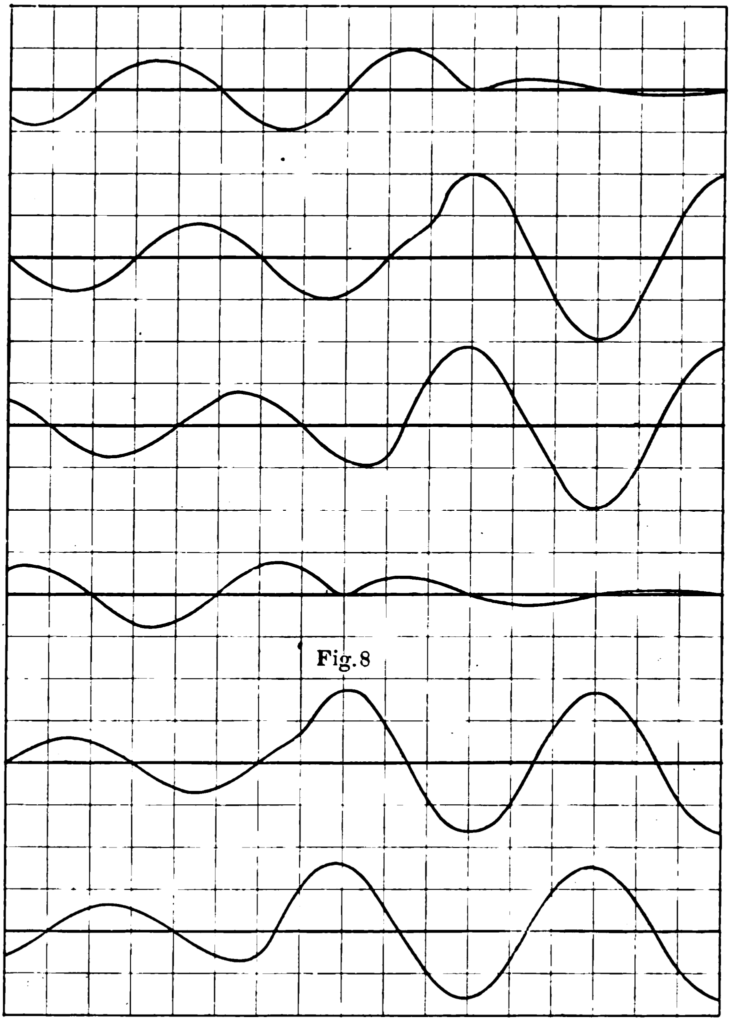

Fig. 8

Traveling waves resulting from this electrostatic induction are usually of lesser voltage, but their origin is of greater local extent; that is, they do not cause local destruction at the point of origin, but travel considerable distances, and their effect is therefore far more generally felt through the system. They probably are the most common manifestation of atmospheric electricity in electric circuits.

Through the electrostatic capacity between primary and secondary of transformers, these impulses frequently enter secondary circuits at an intensity increased by partial reflection at the transformer, and may even lead to sparks jumping from secondary wires to ground, as gas and water pipes, thus constituting a certain fire-risk, which can be completely eliminated by permanently grounding the secondary circuit.

c. Discharges of slowly accumulated potential, resulting in a series of successive impulses.

d. Any spark discharge from the line to another line or to the ground.

e. an arcing ground on one phase of an insulated system, or in general the existence of a " self-rupturing arc " in the system. As explained on former occasions, an arc, when shunted by capacity, as an arc between one conductor of an insulated transmission line and the ground, or between a conductor and the armour of an under-ground cable, is self-rupturing; that is, blows itself out explosively, due to the characteristics of the arc, and hence produces an impulse. An arcing ground thus sends out a series of impulses. Due to the very rapid succession and considerable power—the $\frac{e^2C}{2}$ of the system—these impulses are very serious electric disturbances of the system, and frequently lead to a low-frequency surge and result in extensive destruction. In their appearance in the station, they are very similar to *b* except of greater intensity and rapidity, and therefore are more dangerous.

f. Sudden changes of load, connection and disconnnection of apparatus, etc., also cause impulses. For instance, when connecting a dead transformer to the system an impulse traverses the transformer, and usually penetrates beyond the transformer into the circuit.

3. *Standing waves, oscillations, and surges.*

6. In water, standing waves are less frequent and prominent appearing in general only as stationary ripples in small pools. They form when a wave-train is reflected and thrown back by an obstruction, and the returning wave and the incoming wave

meet. Then at some places the waves neutralize each other and form a node; at others they add to a wave-crest, of greater height than the traveling wave. Figs. 5 to 8 show the gradual change from an impulse to a traveling wave-train, and from the traveling wave to the standing wave or oscillation. Wave formation takes place only in large bodies of water, in which the wave length is small compared with the total path of wave travel, and the boundary usually too irregular to give good reflection and so to allow standing waves to form. Standing waves, however, are the vibration of a tuning fork, or a violin string, or of the air in an organ pipe. Since the velocity of propagation of an electric wave is very high, 188,000 miles per second, even with very long transmission lines, oscillating as a single standing wave, or at fundamental frequency, the period of oscillation is relatively short, the frequency hundreds of cycles per second. In this respect, an electric circuit is rather more analogous to a violin string or the body of air in an organ pipe, and has the same tendency to form regular standing waves or oscillations. Just like a violin string, the electric circuit may oscillate either as single wave without nodes, or a number of nodes form, and the different sections oscillate separately, at higher frequencies.

This phenomenon of standing waves, or oscillations in transmission lines, has been investigated repeatedly. It is usually approached by considering the distribution of current and potential in a circuit of distributed capacity, inductance and resistance.*

The standing wave is produced by the superposition of a wave and its reflected wave, and the general equations result from equation (3) by combining the impulse with the reflected impulse. Since the production of an oscillation or standing wave presupposes a slow decay of the wave train; that is, b_k must be small, an approximate value is derived by suppressing the term $\varepsilon^{-b_k t}$. This means, neglecting the gradual dying out of the wave, that is, considering it as alternating instead of oscillating. The trigonometric function of time can then be eliminated by the introduction of the complex quantity, and the equation of the standing wave, or oscillation, becomes:

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*See Steinmetz, Alternating Current Phenomena, third edition, page 181.

$$E = \varepsilon^{-r\sqrt{\frac{\pi}{2}\frac{C}{L}}\,u} \sum_{1}^{\infty} {}_k A_k \left(\cos\frac{k\pi u}{2} + jk \sin\frac{k\pi u}{2} \right)$$

$$= \varepsilon^{+r\sqrt{\frac{\pi}{2}\frac{C}{L}}\,u} \sum_{1}^{\infty} {}_k B_k \left(\cos\frac{k\pi u}{2} - jk \sin\frac{k\pi u}{2} \right) \tag{4}$$

$$I = \sqrt{\frac{C}{L}} \left\{ \varepsilon^{-r\sqrt{\frac{\pi}{2}\frac{C}{L}}\,u} \sum_{1}^{\infty} {}_k A_k \left(\cos\frac{k\pi u}{2} + jk \sin\frac{k\pi u}{2} \right) \right.$$

$$\left. + \varepsilon^{+r\sqrt{\frac{\pi}{2}\frac{C}{L}}\,u} \sum_{1}^{\infty} {}_k B_k \left(\cos\frac{k\pi u}{2} - jk \sin\frac{k\pi u}{2} \right) \right\}$$

where:

L = inductance,

C = capacity,

r = resistance,

per unit length of line, and

A_k and B_k are complex constants.

The lowest frequency of oscillation of a line is the frequency which makes the line a quarter wave-length. That is, if:

l = length of line,

v = velocity of light,

It is:

$$N_0 = \frac{v}{4\,l} \tag{5}$$

$$= \frac{47000}{l}$$

If l is given in miles.

From the line constants this fundamental frequency can be expressed, approximately, by:

$$N_0 = \frac{1}{4\sqrt{L_0\,C_0}} \tag{6}$$

where:

$L_0 = lL =$ total inductance,

$C_0 = lC =$ total capacity of the line.

In addition to the fundamental frequency L_0, all its odd higher harmonics, or any frequency:

$$N = (2k - 1) N_0 \tag{7}$$

may exist.

7. In general, an oscillation of a transmission line is a complex wave, containing fundamental and higher harmonics. The relative proportions of the different harmonics in the oscillating wave depend upon the distribution of potential and of current at the moment of the start of the oscillation.

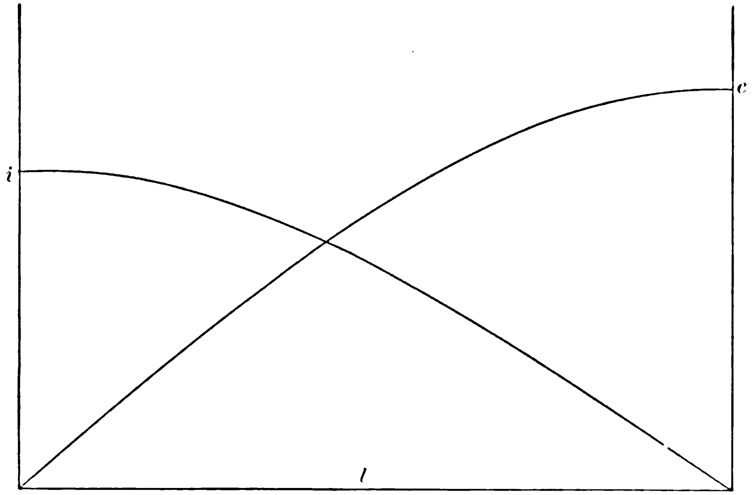

Fig. 9

If the distribution of potential and of current at the start of the oscillation were perfectly sinusoidal, as shown by Fig. 9, only the fundamental wave would appear. The more irregular the distribution is, the more prominent are the higher harmonics; with a very irregular and abrupt distribution, the fundamental wave does not appear at all, but only higher harmonics.

A transmission line thus has not only one frequency of oscillation, as a combination of condenser and separate inductance, but an infinite number of frequencies, of which one is the lowest or fundamental, the others its odd multiples or higher harmonics.

These frequencies depend on the resistance, inductance, and capacity of the line. Neither of these quantities is entirely constant. For instance, at high voltage the capacity increases by electrostatic glow, brush discharges and streamers; inductance and resistance vary with the unequal current distribution throughout the section of the conductor, etc., so that at the very high harmonics, which are close together—for instance, the 199th and the 201st harmonics differ in frequency by 1% only—the gap between successive harmonics is bridged by the variability of the frequency, and a line for very high frequencies thus can oscillate at any frequency whatever. In other words, a transmission line can oscillate at a fundamental frequency, the lower higher harmonics thereof, and at any very high frequency whatever; that is, the line has definite frequencies of oscillation only at low and moderate frequencies, but not at very high frequencies. This is analogous to the formation of other standing waves.

8. The oscillation is the phenomenon by which in an electric circuit after a disturbance of the circuit conditions the flow of power restores its equilibrium. Any circuit disturbance may, and usually does, produce an oscillation which may be local only, that is, contain only the very high-frequency harmonics, if the disturbance is local; but it may become universal by including the fundamental and the lower harmonics. In the latter case it is usually called "surge."

In some respects, therefore, the oscillation is a result of a disturbance, as an impulse, and the power which oscillates is the generated power of the circuit; hence the possible destructiveness of the oscillation is limited only by the available power of the generating system, but does not directly depend upon the severity of the disturbance which caused the oscillation.

The power, which oscillates, is the energy stored by the flow of generated power in the electric field of the transmission line, as electromagnetic energy: $\frac{i^2 L}{2}$, and as electrostatic energy: $\frac{e^2 C}{2}$, and the shorter the section of line which oscillates the higher is the frequency of the oscillation. The smaller, however, is also the power and the destructiveness of the oscillation, and considerable damage results, therefore only from low-frequency oscillations; that is, oscillations of the whole or a large part of the system. Local high-frequency oscillations are dangerous chiefly by their liability to destroy insulation by puncture, and to produce a low-frequency surge of higher power.

Since, as a rule, the maximum amount of energy which can be stored in the electric field of a circuit is the electromagnetic energy of the short-circuit current, $\frac{i_0^2 L}{2}$, the short-circuit surge is the most powerful and destructive.

Some typical forms of oscillations are:

a. Spark discharges to and from the line, as over some lightning-arresters; the breaking up of a traveling wave when entering the station, etc., result in the formation of very high frequency oscillations, millions of cycles per second.

b. Arcing grounds and other arc discharges to ground from a line of an insulated system; reflected traveling waves, etc., give oscillations which, while still of very high frequency, reach considerably further down in frequency than *a*, hundred thousands of cycles per second.

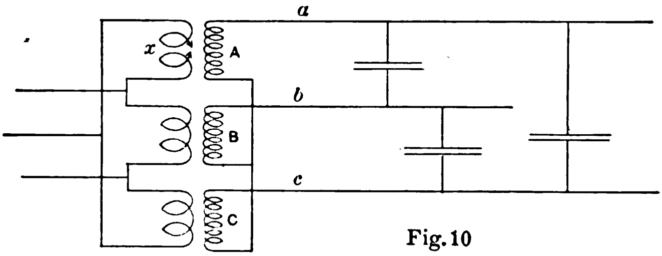

Fig. 10

c. Charge and discharge of the line, as when discharging an accumulated electric charge over a path of low resistance; connecting a dead transformer into the circuit, etc., results in high-frequency oscillations containing also an appreciable low-frequency component.

d. In general, changes of circuit conditions, as sudden changes of load; connecting or disconnecting a transmission line; opening a short circuit suddenly, etc., give oscillations in which the fundamental frequency predominates.

e. Low-frequency surges, consisting primarily of the fundamental wave, may be produced by certain transformer connections in polyphase systems, in which in case of an accident, an unequal distribution of load, or other causes, the open circuit inductance of a transformer coil is in series with the line capacity, in the circuit of a live transformer. Typical hereof is the case of a delta-star connected system without grounded neutral, if one of the sides of the delta is open circuited, as shown as X in Fig. 10. The high-tension coil A of this transformer is in series with the line capacity, $a-c$, in the circuit of transformer B, and in series with the line capacity, $a-b$, in the circuit of transformer C. In this case the voltage between a and the other two lines b and c is practically unlimited. A number of such transformer connections exist, and in their use this phenomenon should be guarded against.

9. Looking at the oscillation as surge of energy between the electromagnetically stored energy, $\frac{i^2 L}{2}$, and the electrostatically stored energy, $\frac{e^2 C}{2}$, it can well be seen, that the electrostatic energy is far more limited than the electromagnetic energy; and the maximum possible energy, which can be stored in the electric field is the electromagnetic energy of the short-circuit current, as stated above. The most powerful oscillation is therefore the short-circuit surge of a system, or oscillation produced by instantaneously rupturing a short circuit, as by a self-rupturing arc. In this surge the fundamental predominates, and the equations of the surge potential are:

$$e = i_0\sqrt{\frac{L}{C}} \{1.26 \cos\omega \sin\phi + 0.40 \cos 3\omega \sin 3\phi + 0.22 \cos 5\omega \sin 5\phi + 0.13 \cos 7\omega \sin 7\phi + 0.07 \cos 9\omega \sin 9\phi + 0.03 \cos 11\omega \sin 11\phi + \dots\} \quad (8)$$

where:

i_0 = short-circuit current

L = inductance of line

C = capacity of line

$$\omega = \frac{\pi u}{2 l} \quad (9)$$

l = length of line,

u = distance along line, from point where the short circuit was ruptured, as zero point.

$$\phi = 2\pi N t \quad (10)$$

t = time

$$N = \frac{1}{4\sqrt{L\,C}} = \text{frequency of fundamental wave of oscillation.} \tag{11}$$

For instance, for a line of 50 miles, consisting of wire No. 0000, and transmitting 30,000 volts at 25 cycles, it is, approximately:

$L = .2\ h$, hence:
$x = 2\pi N_0 L = 31.4$ ohms
$C = 0.4$ mf., hence:

$$N = \frac{1}{4\sqrt{L\,C}} = 880 \text{ cycles.}$$

$$\sqrt{\frac{L}{C}} = 707$$

$r = 26$ ohms,
hence:

$$z = \sqrt{r^2 + x^2} = 40.8 \text{ ohms,}$$

and, assuming that the supply voltage, with a short circuit at the other end of the line, drops instantly to one third, or $e_0 = 10,000$ volts:

$$i_0 = \frac{e_0}{z} = 245 \text{ amperes.}$$

hence the surge voltage:

$$e = 174,000 \left\{ 1.26 \cos \omega \sin \phi + 0.40 \cos 3\omega \sin 3\phi + 0.22 \cos 5\omega \sin 5\phi + \ldots \right\} \text{ volts.}$$

At:

$$i_0 = 245 \text{ amperes,}$$

this gives the power of the oscillation:

$$e\,i_0 = 42,500 \text{ kilovolt-amperes.}$$

Standing waves or oscillations in electric circuits vary from the very low frequency of the fundamental surge of very long transmission lines, which approaches commercial alternating-current frequencies, to frequencies of several hundred million cycles per second, in the discharge oscillation between the cylinders of a multi-gap lightning arrester. Due to this enormous range of frequency, the physical effect of the oscillation also varies greatly. In very high frequency oscillations the power is very small; the electrostatic effects, as luminous glow, brush discharge, streamers and sparks, are prominent, but the direct damage usually insignificant, and the effect local. Inductance opposes a fairly effective barrier. On the other extreme, low-frequency surges show little or no luminous display; inductance offers no obstruction, but due to their high power and wide extent, considerable damage may be done all over the system.

Oscillations therefore are frequently subdivided into high-frequency oscillations, in which the lower harmonics are absent, and low-frequency oscillations, in which the fundamental predominates, The name surge is frequently applied to denote the latter.

Between these two extremes, however, the low-frequency surge and the high frequency oscillation, oscillations of intermediate frequency are found—against which inductances do not give sufficient protection—which have considerable power, and also give luminous displays, as streamers and brush discharges. Oscillations of this intermediate class are occasionally given by arcing grounds, spark discharges through defective joints in large cable systems, etc.

10. The four types of lightning disturbances here discussed: static charge, impulse, oscillation, and surge, may occur singly, in groups, or all occur together, or rather successively, the one preceding and causing the other. A static charge, for instance, rises, until it breaks through to ground and discharges, thus producing an impulse or traveling wave.

A traveling wave breaks at a station, and produces high-frequency oscillations.

A high frequency oscillation, puncturing the insulation, causes a short circuit, which ruptures itself, and thus produces a low-frequency surge.

A static charge, discharging over lightning-arresters with insufficient damping, causes a high-frequency oscillation.

A static charge, short circuiting the system by its discharge, causes a low frequency surge.

Lightning-arresters, when discharging a high-frequency oscillation, may fail to hold back the machine current, and the short circuit resulting therefrom produces a low-frequency surge.

All four types of disturbances may occur successively:

An electrostatic charge rises until it breaks down to ground, thereby starting an impulse. This impulse at the entrance to a station breaks up in high-frequency oscillations. These oscillations puncture the insulation and produce a short-circuit surge.

The traveling wave produced by connecting a cable to the bus-bars may cause a spark discharge from conductor to cable armour at some defective joint. This spark develops into an oscillating arc, which sends out traveling waves along the cable. These; when entering the station, produce high-frequency oscillations, and systems of such oscillations follow each other with great rapidity, produced by the successive impulses caused by the oscillating arc, and produce a continuous " static " in the station, which ultimately produces somewhere a short circuit, and so a low-frequency surge.

In short, the number of combinations of such phenomena is unlimited.

11. The problem of lightning protection then is threefold.

1. Prophylactic; to guard against the entrance or origin of disturbances.

2. Restrictive; to guard against a disturbance leading to other disturbances.

3. Curative; to discharge a disturbance harmlessly:

As seen, the problem is a vast one, and comprises nearly every part of design, installation, and operation of the system.

1. Prophylactic; against entrance of atmospheric disturbances The location of the transmission line should be chosen so as to avoid exposed positions as far as possible. A grounded overhead wire of good conductivity offers considerable protection. Grounded side wires increase the protection and discharge side drift. The question of barbed wire against plain wire also is still open to discussion. Emergency arresters in the lines or arresters at intermediate stations may shunt traveling waves toward ground.

Grounding the neutral of the high-potential circuit offers some protection against static charges and against arcing grounds, but increases the liability to short circuits and shutdowns due ot other causes.

A study of transformer connections and their operating conditions, of generator wave-shape and connections, of the possible origin of higher harmonics of the potential wave, the construction and location of underground cables, the protection of their joints, the desirability, size and location of reactive coils—all are subjects requiring careful consideration from the point of view of lightning protection. In short, the most important problems of lightning protection are met and should be solved before the question of lightning arresters is approached.

The problems 2 and 3, to limit the disturbance, so that it does not cause other and possibly more severe disturbances, and to discharge it safely, are the problems which the designer of the lightning-arrester has to solve. I understand that these will be taken up in the other papers announced for this evening.

A paper to be presented at the 219th meeting of the American Institute of Electrical Engineers, New York, May 24, 1907.

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(*Subject to final revision for the Transactions.*)

ZIGZAG LEAKAGE OF INDUCTION MOTORS.

BY R. E. HELLMUND

Various formulas have been given heretofore for the predetermination of the leakage coefficient of induction motors, but the results derived from these formulas are so divergent that the formulas themselves are rather discredited. It seems to the writer that the following study about the values of the zigzag leakage may help to clear this somewhat unsettled question.

In the study of induction motors the leakage coefficient is one of the most important factors, and therefore this value will be chiefly discussed in what follows. Unfortunately the definition of this value is very unsettled in practice. Some writers when deriving the induction motor theory introduce the leakage coefficient as a ratio of magnetic reluctances in the motor, and others introduce it as a ratio of fluxes which exists while no secondary reactance takes place. These two different definitions may be represented by the two following equations:

$$\frac{R_s}{R_p} = \tau_1 \tag{1}$$

where R_s = the reluctance of the flux being interlinked with the secondary windings, R_p = the reluctance of the flux being interlinked with the primary winding, and τ_1 = the primary leakage coefficient.

$$\frac{F_p}{F_s} = \tau_2 \tag{2}$$

where F_p = the flux being interlinked with the primary winding, F_s = the flux being interlinked with the secondary winding, and τ_2 = the primary leakage coefficient.

Two other definitions which are frequently used are as follows:

$$\frac{R_p}{R_e} = \tau_3 \tag{3}$$

where R_p is again equal to the reluctance of the total flux interlinked with the primary winding, R_e = the reluctance of that part of the flux which is interlinked with the primary winding, but not with the secondary winding, and τ_3 the primary leakage coefficient.

$$\frac{F_e}{F_p} = \tau_4 \tag{4}$$

where F_p = again the total flux interlinked with the primary winding, F_e = that part of the flux which is interlinked with the primary winding, but not with the secondary winding, and τ_4 = the primary leakage coefficient.

Since

$$F_p = F_s + F_e$$

we may easily find

$$\tau_2 = \frac{1}{1 - \tau_4}$$

Similarly a relation between τ_1 and τ_3 may be established.

It is therefore always possible to find the values τ_1 and τ_2 if τ_3 and τ_4 are known, so it will be sufficient to deal in the following with the two latter values only. For instance, a three-phase motor with one slot per pole per phase in both members has been chosen. Fig. 1 shows the arrangements of the slots and windings, and the rotor in such position that the stator and rotor teeth do not coincide. It is simple to trace all the possible paths of the magnetic fluxes as shown by dotted lines. Moreover, in order to find the values of all the existing fluxes it is simplest to treat the magnetic circuits as electric circuits. Fig. 2 gives the magnetic circuits reproduced from Fig. 1 as electric circuits. In all places where a flux passes through air a resistance has been introduced, while the practically very small reluctance of the magnetic paths in the iron has been neglected. The magnetomotive force which the primary magnetizing current impresses upon the primary teeth has been replaced by electromotive forces, E_1, E_2, and E_3. It can be easily shown that the magnetomotive forces in opposite teeth must be equal in value and in direction, and therefore that all currents respectively fluxes in directly opposite parts of the system

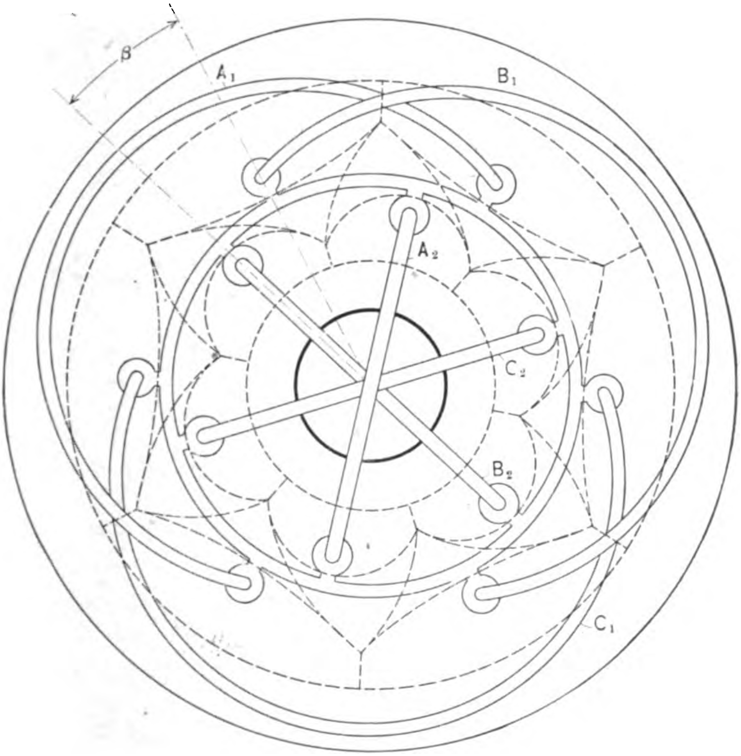

Fig. 1

must be equal in value and opposite in direction. This has been taken into account in numbering the circuits and in assuming the current direction as indicated by arrows.

It would now be possible to find all the values of the various fluxes and then to determine the value of the zigzag and slot leakage together. The zigzag leakage alone may be found simply by omitting the slot leakage fluxes in the further calculation, although thereby a small error in the values of the primary fluxes is introduced, the same is of no practical importance at all, the slot leakage being mostly less than 1% of the total primary field. It is obvious from the figures that the resistances of the circuit 4, 5, and 6 are equal, and that also the resistances of the circuits 8 and 9 are equal. If, therefore, we put

$$r_4 = r_5 = r_6 = b$$
$$r_7 = r_8 = r_9 = a$$

and
we find from Fig. 2

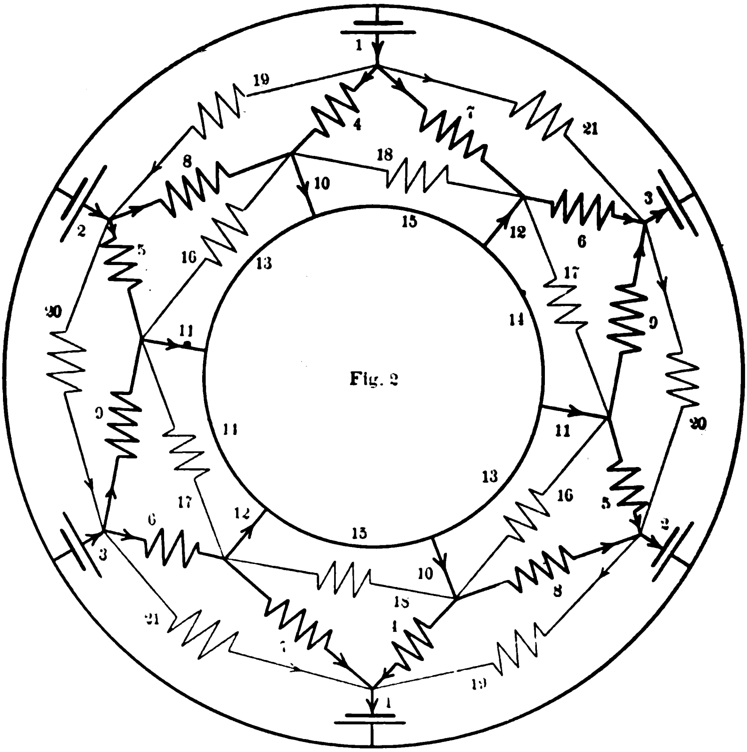

Fig. 2

$$E_1 - F_4 b + F_8 a - E_2 = 0$$
$$E_2 - F_5 b + F_9 a - E_3 = 0$$
$$E_3 - F_6 b - F_7 a + E_1 = 0$$

and

$$F_4 b - F_7 a = 0$$
$$F_5 b - F_8 a = 0$$
$$F_6 b - F_9 a = 0$$

From this we find

$$\left.\begin{aligned} F_1 &= E_1\left(\frac{1}{a}+\frac{1}{b}\right) \\ F_2 &= E_2\left(\frac{1}{a}+\frac{1}{b}\right) \\ F_3 &= E_3\left(\frac{1}{a}+\frac{1}{b}\right) \end{aligned}\right| \qquad (5)$$

and

$$\left.\begin{aligned} F_{10} &= \frac{E_1}{b}+\frac{E_2}{a} \\ F_{11} &= \frac{E_2}{b}+\frac{E_3}{a} \\ F_{12} &= \frac{E_3}{b}-\frac{E_1}{a} \end{aligned}\right| \qquad (6)$$

Now we know that the currents flowing in the primary windings are 120°, shifted against each other, and may with open secondary circuits assumed to be sinusoidal.

It may be

$$\begin{aligned} i_{b1} &\equiv \cos(x+240) \\ i_{a1} &\equiv \cos x \\ i_{c1} &\equiv \cos(x+120) \end{aligned}$$

We find, therefore, the magnetomotive forces

$$\left.\begin{aligned} E_1 &= \cos x+\cos(x+240) = -\cos(x+120) \\ E_2 &= \cos x \\ E_3 &= \cos x+\cos(x+120) = -\cos(x+240) \end{aligned}\right| \qquad (7)$$

It follows now from 5 and 7

$$\left.\begin{aligned} F_1 &= -\cos(x+120)\left(\frac{1}{a}+\frac{1}{b}\right) \\ F_2 &= \cos x\left(\frac{1}{a}+\frac{1}{b}\right) \\ F_3 &= -\cos(x+240)\left(\frac{1}{a}+\frac{1}{b}\right) \end{aligned}\right| \qquad (8)$$

and from 6 and 7

$$\left.\begin{aligned} F_{10} &= -\frac{\cos(x+120)}{b} + \frac{\cos x}{a} \\ F_{11} &= \frac{\cos x}{b} - \frac{\cos(x+240)}{a} \\ F_{12} &= -\frac{\cos(x+240)}{b} + \frac{\cos(x+120)}{a} \end{aligned}\right| \qquad (9)$$

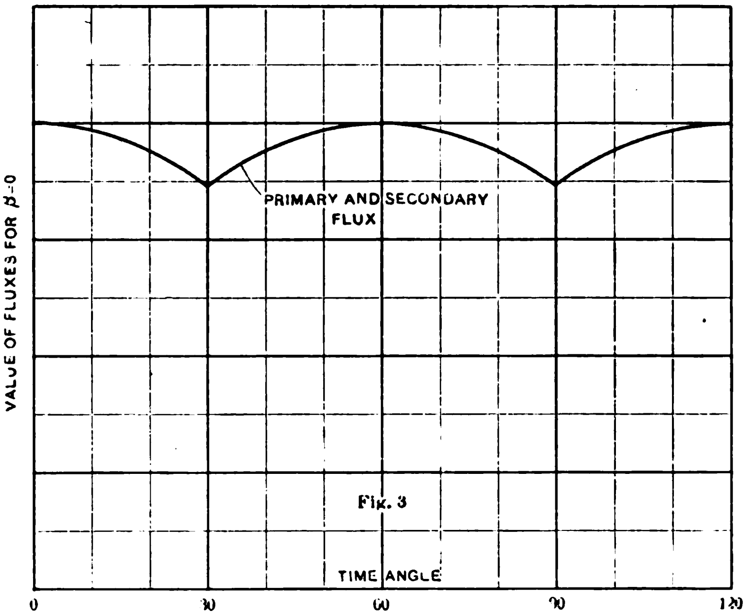

Fig. 3

It is now obvious that after the values a and b have been determined from Fig. 1 for a certain rotor position, the primary flux may be found for any time-angle, x, by simply adding arithmetically the values being found for F_1, F_2, and F_3 for this time-angle; in the same way the secondary flux may be found by adding the values of F_{10}, F_{11}, and F_{12}.

In Fig. 3 the primary and secondary flux as found in this way have been given as a function of the time for the rotor position for which the angle β, Fig. 1, is 0.

As will be seen, both fluxes change with the time,* but primary and secondary fluxes are always equal; this means that for this rotor position no zigzag leakage flux exists, and the leakage coefficient $\tau_4 = 0$.

In Fig. 4 the primary and secondary fluxes are given for a rotor position for which $\beta = 15°$; that is, for a position where the rotor slots are shifted about one-quarter tooth against the stator slots. It will be seen that both fluxes change again with the time, but their values are now different from each other. It is obvious that at any moment the difference between the primary and secondary fluxes represent the leakage flux. Fig. 5 gives the value of τ_4 as function of the time as found from Fig. 4. The maximum value of τ_4 is for this rotor position about 0.177, and the average value may be found to be about 0.097.

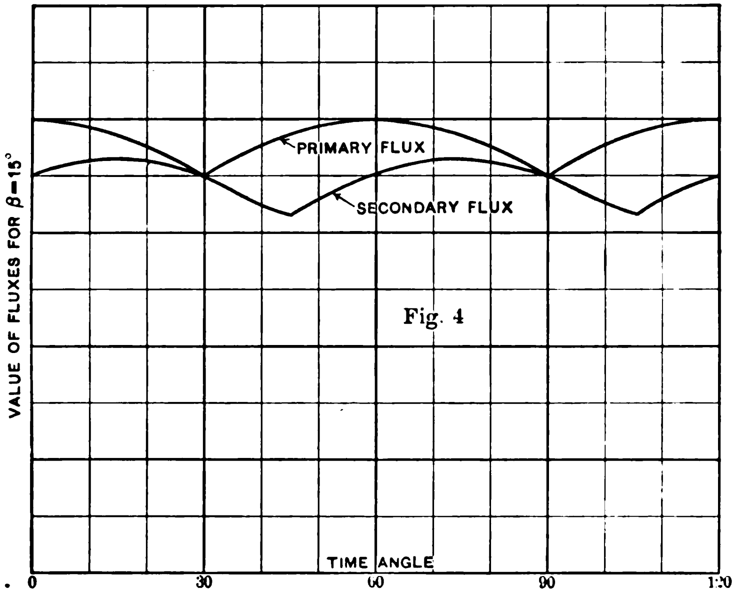

Fig. 4

Figs. 6 and 7 give the same curves as Figs. 4 and 5, but for a rotor position for which $\beta = 30°$; that is, for a position where the rotor slots are shifted about one-half tooth against the stator slots.

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* See study about the rotating field, *Electrical Review*, September 22, 1906.

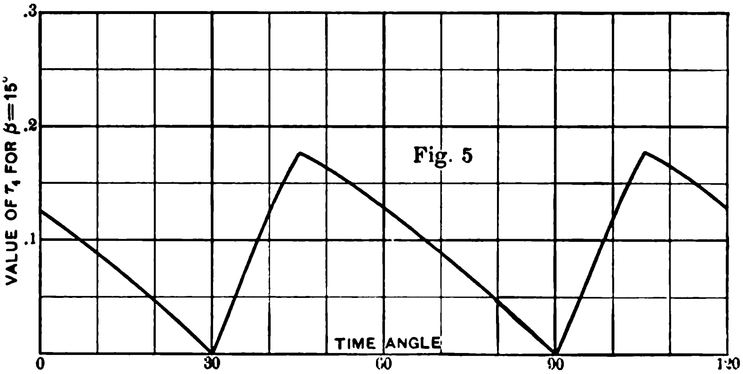

Fig. 5

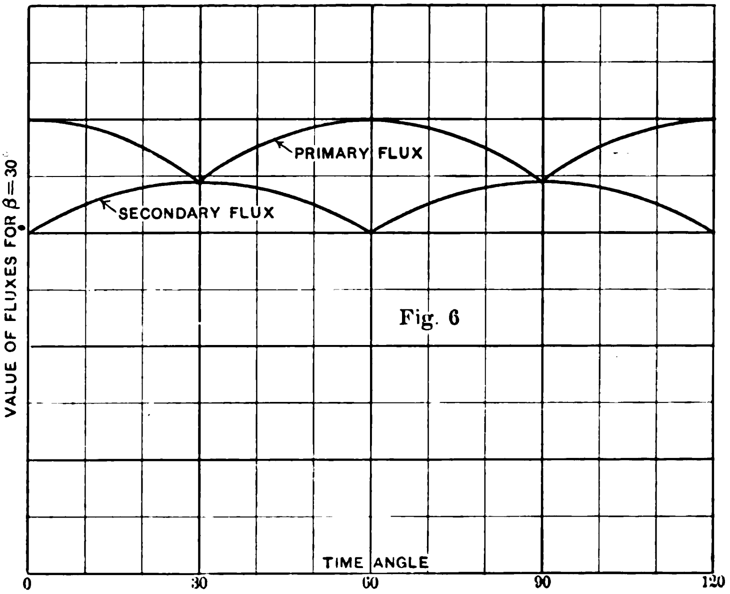

Fig. 6

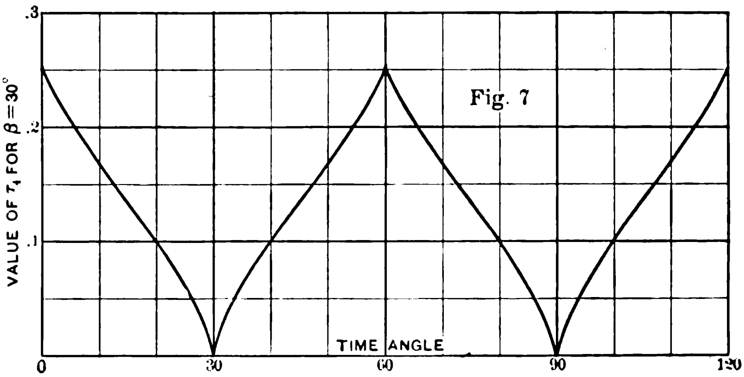

Fig. 7

In this case the maximum value of $\tau_4 = 0.25$, while the average value may be found to about $\tau_4 = 0.134$.

It remains now to find what influence the magnetic leakage as found before has upon the value of the potentials being induced in the secondary circuits.

The potential induced in coil A_1 will be

$$e_{a1} \equiv \frac{d\,(F_1+F_2+F_3)}{d\,x}$$

or

$$e_{a1} \equiv \frac{d\,(E_1+E_2+E_3)}{d\,x} \left(\frac{1}{a}+\frac{1}{b}\right) \tag{10}$$

or

$$e_{a1} \equiv \frac{d\,(2\cos x)}{d\,x} = -\ 2\sin x$$

For the potential induced in coil A_2 we find in a similar way,

$$e_{a2} \equiv \frac{1}{a}\,(-\ E_1 + E_2+E_3) + \frac{1}{b}\,(E_1+E_2+E_3)$$

or

$$e_{a2} \equiv \frac{1}{a}\,\frac{d\,[2\cos\,(x-60)]}{d\,x} + \frac{1}{b}\,\frac{d\,(2\cos x)}{d\,x}$$

$$e_{a2} \equiv -\frac{2}{a}\sin\,(x-\ 60) - \frac{2}{b}\sin x \tag{11}$$

It is now simple to find the maximum value of the potential in coil A_1,

$$e_{a1}\ \text{max.} \equiv 2$$

and the effective potential in coil A_1

$$e_{a1}\ \text{eff} \equiv \frac{2}{\sqrt{2}} \tag{12}$$

The maximum value of the potential in coil A_2 is obtained for

$$\frac{2}{a}\cos\,(x-60) \equiv -\frac{2}{b}\cos x \tag{13}$$

It is now possible to find for any ratio of a to b; that is, for any rotor position from 13 the value of x for which the secondary potential reaches its maximum e_{a_2} maximum. Curve *A* in Fig. 8 gives the relation between the rotor position and the time-angle x, for which the secondary potential reaches the maximum value. After this curve has been determined, it is possible to find from 11 the maximum and the effective potential induced in the secondary winding. Curve *C* gives the secondary potential as found for different rotor positions. Curve *B* gives the primary potential as found from 12; the same is, of course, independent of the rotor position, on the assumption that the air-gap is uniform and that the influence of the slot

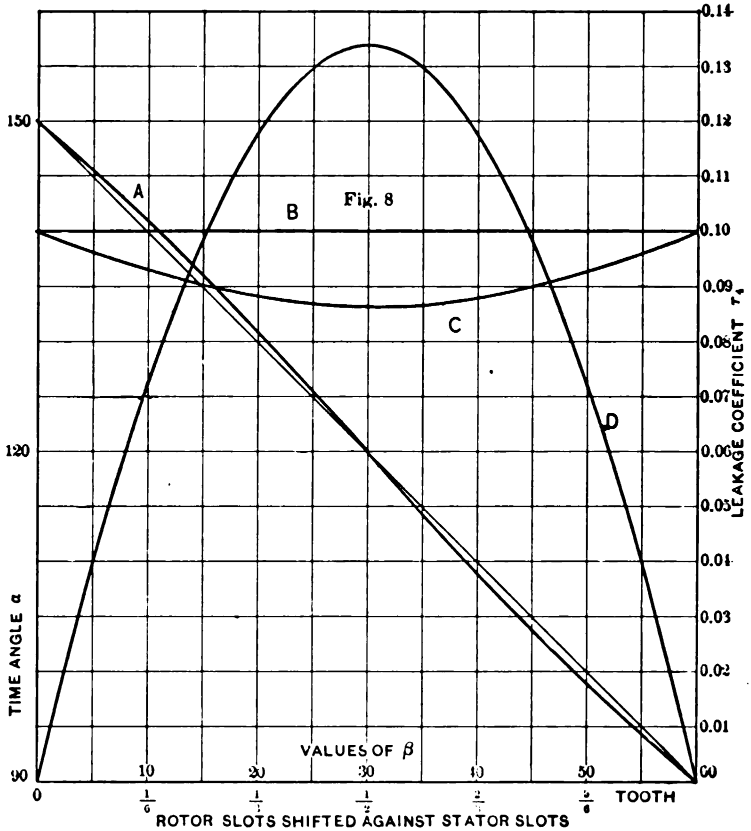
Fig. 8

openings may be neglected. Curve *D* represents the following value:

$$y \equiv \frac{e_{a_1} \text{ eff} - e_{a_2} \text{ eff}}{e_{a_1} \text{ eff}}$$

where the value of e_{a_1} effective and e_{a_2} effective are taken from Curve *B* and *C*.

A comparison of the average values for τ_4 as found from Figs. 3 to 7, with the values of y for the same rotor positions, shows that

$$\tau_4 \equiv y$$

This shows for the case under consideration the correctness of the partly customary method for determining the leakage coefficient τ_4 from tests, which consists in testing the primary and secondary potential of a motor and in assuming,

$$\tau_4 = \frac{e_{a_1} \text{ eff} - e_{a_2} \text{ eff}}{e_{a_1} \text{ eff}} = \frac{F\,e}{F\,p}$$

As average value for τ_4 we find from Curve *D*,

$$\tau_4 \text{ average} \equiv 0.081.$$

The fact that Curve *D* is not a straight line shows that it is not admissable to assume the leakage coefficient equal to the average of its maximum value and its minimum value, as has been done by various authors. The mistake which would thereby be introduced in the case under consideration is quite considerable. The average of the maximum value of τ_4 and its minimum is

$$\frac{0+0.134}{2} = 0.067;$$

that is, about 20% different from the real average value 0.081.

It remains now to find the value of 3 for comparison. Fig. 9 shows the rotor in its position for $\beta = 30$. A glance on this figure shows that τ_3 according to its previously given definition is 0.333 = $\frac{1}{3}$, since the total primary flux of course passes through three teeth, while the leakage flux passes through ($2\times\frac{1}{2}$) tooth only. The ratio of the resistances of the two paths is therefore

$$\tau_3 = \frac{\frac{1}{3}}{2\times\frac{1}{2}} = \frac{1}{3}$$

The value of τ_4 for the same position was 0.134, and we see therefore that τ_4 and τ_3 are two entirely different values; in the case under consideration their difference amounts to more than 100%. This shows that it is of the highest importance in any study of the induction motor to make a strict distinction between the two values.

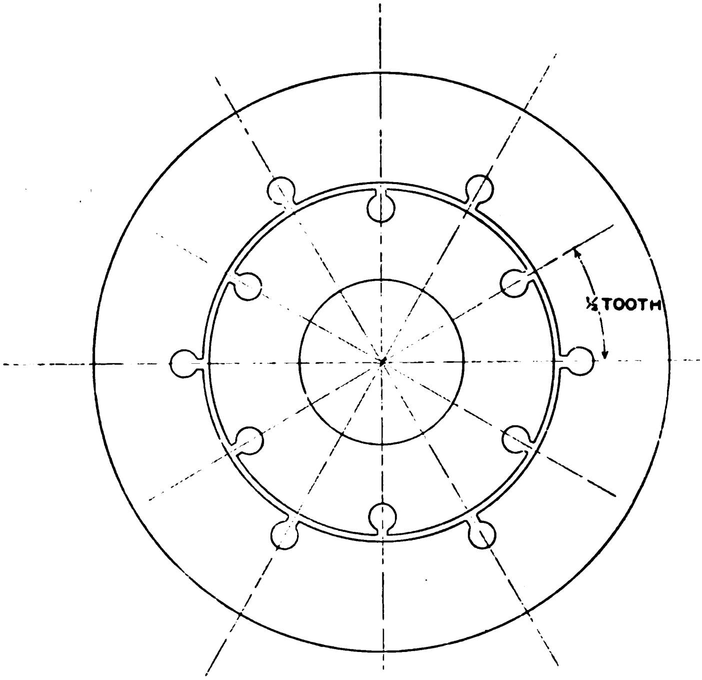

Fig. 9

The explanation of the phenomena causing the difference between τ_3 and τ_4 is comparatively simple. It is obvious that if the magnetomotive force and therefore the density over one pole face should be uniform, the values τ_3 and τ_4 would be equal. Since, however, the magnetomotive forces and, therefore, the densities near the pole limits are considerably smaller than near the center of the pole, it is obvious that the flux near the pole limits which forms that part of the flux which does not thread the secondary windings (*i.e.*, the leakage flux) must be much smaller than it would be in case of a uniformly distributed field.

It seems to the writer that in deriving the diagram of the induction motor the value τ_4 should be used, since for the field diagram the actual ratio of the various fields and not that the reluctance of their paths is of interest. To introduce the value of τ_3 as leakage coefficient, as has been done by Heyland, Behn-Eschenburg, and others, is not correct unless another coefficient giving some ratio between the magnetomotive force of the main field and that of the leakage fields be introduced. The previous considerations apply, of course, to the zigzag leakage only, but it is obvious that similar facts apply to the other kinds of leakages.

The previous considerations were dealing with the leakage coefficient as determined on the assumption that no secondary reaction takes place. The coefficient τ_4 as previously determined would be the right value upon which the theories for the load conditions might be based, if the secondary reaction would be caused by sinusoidal secondary currents only for all load conditions. For the blocked rotor condition of the motor, that is, for the starting condition, this condition is fulfilled. Assuming that sinusoidal electromotive forces are impressed upon the motor we have found that all the fluxes in the motor are sinusoidal functions of the time, we also have found that the electromotive forces induced in the secondary circuits are sinusoidal. If, therefore, the secondary circuits are closed the currents flowing will be sinusoidal and the reactions caused by secondary currents will be sinusoidal functions of the time.

For all other load conditions the phenomena are not quite as simple. If the field set up by the primary windings had a sinusoidal space distribution over the poles, and if it were constant in value; and if it rotated with uniform speed—then all potentials induced in the secondary and, therefore, the currents in the secondary and the magnetic reactions, would be always sinusoidal, no matter what the speed of rotation of the rotor. This is, however, not the case. The curves given in Figs. 3, 5, and 7, for the total value of the primary field show that the latter varies in its strength.

We also may conclude from the previous considerations that the field does not rotate with uniform speed. If the field rotated with uniform speed, Curve *A* of Fig. 8 would have to be a straight line. The speed of the field as function of the time may be easily found from Fig. 8, Curve *A*, and is shown by Curve *A* in Fig. 10.

It also may be shown that not only the speed of the field as a whole varies, but that the speeds of the various parts of the field are different from each other, and vary with the time. If, therefore, the rotor rotates with a certain speed, the electromotive forces induced in the rotor windings are not only due to the slip, but there are also certain electromotive forces induced by the fluctuations of the strength of the primary field and by the irregularities in the speed of rotation of said field. (There is, of course, a possibility that the irregularities of the strength of the field and those of the speed of the field eliminate each other in their effect upon the secondary windings; it may be shown, however, that this is not the case.)

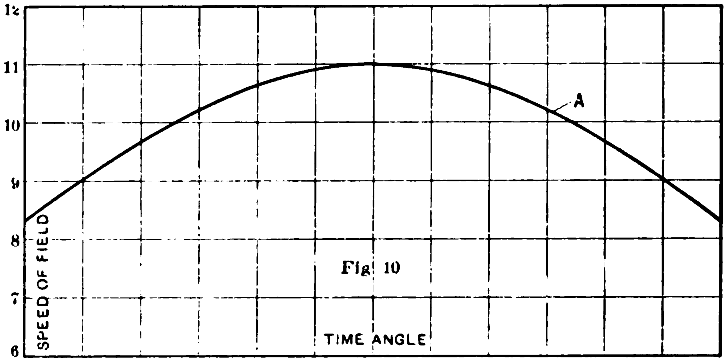

Fig. 10

It seems almost impossible to determine the exact phenomena for all load conditions. It is possible, however, to find pretty exactly what happens while the motor is running under no load. It can be shown that while the rotor is running synchronously with a uniform speed the secondary reaction will cause the field distribution over the pole faces to have a step-form of such a shape that the area of each step is equal to the corresponding area of a sine wave. (See Fig. 11.)

The above causes of the secondary reaction have been partly discussed by other writers. A detailed and pretty complete account of them, as well as a derivation of the field shape for the no load condition has been given by the writer in a study given in *Electrical Review*, September 22, 1906.

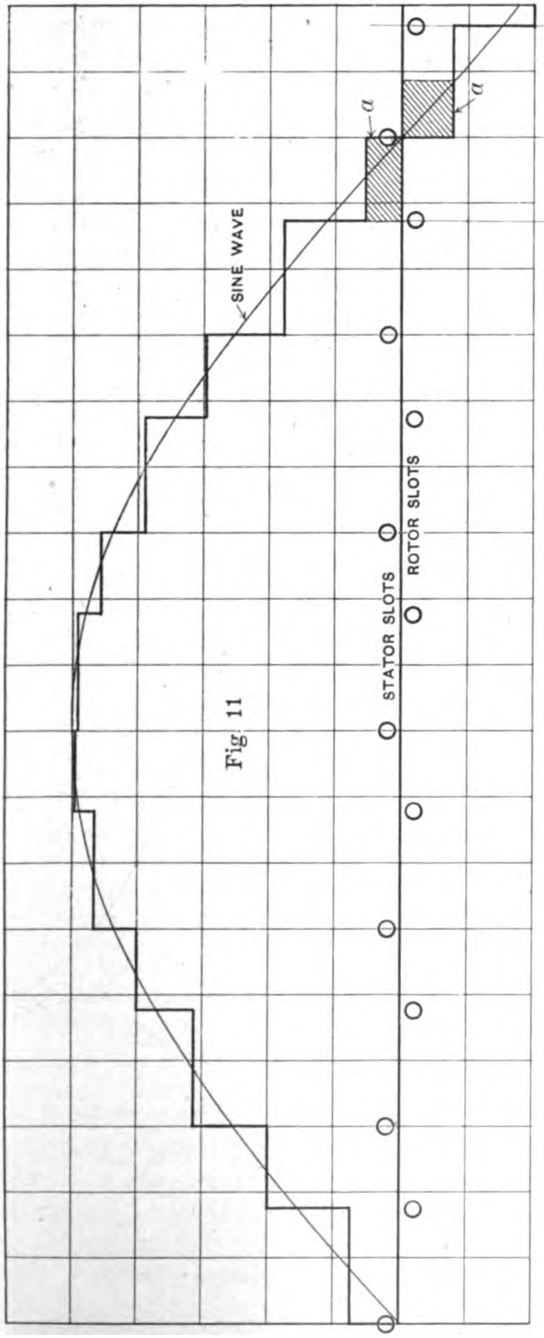

Fig. 11

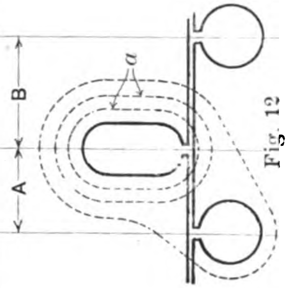

Fig. 12

The fact that the field has a distribution as outlined above gives a very simple way to determine the zigzag leakage coefficient as defined under 4, but for the no-load condition.

If we consider the teeth near the pole limit (Fig. 12), we see that the primary zigzag leakage flux at one pole limit can never be larger than the flux *a* going through the smallest air-gap *A* to the rotor, while except for the rotor position where $A = B$, part of the flux going through the air-gap *B* interlinks with the secondary conductors and only the remaining part *A* is leakage flux. The flux *A* is, however, proportional to the smallest step of the area representing the flux distribution (see Fig. 11). We may therefore define the zigzag leakage coefficient for the light running motor as follows:

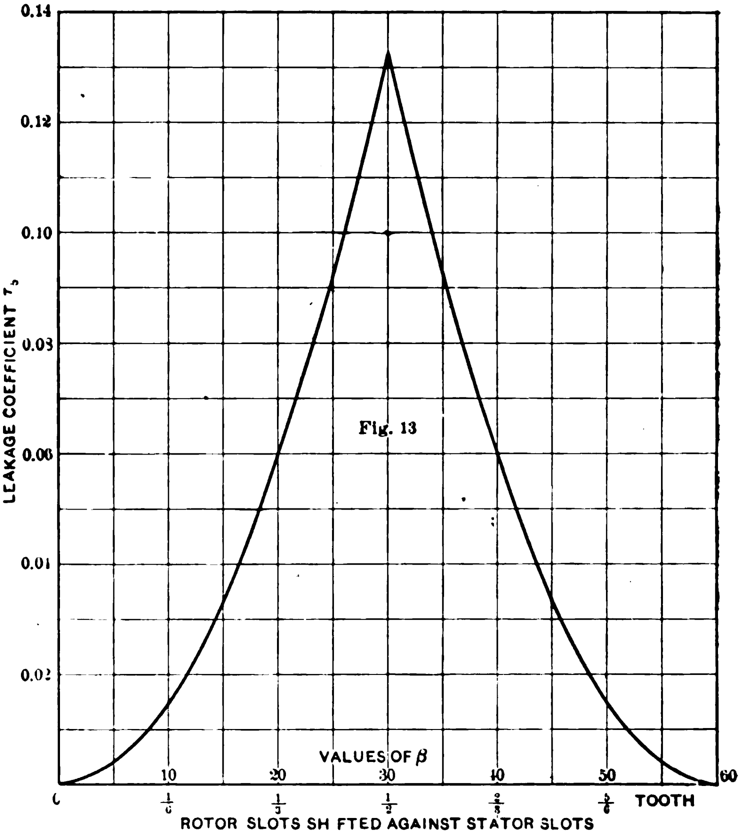

Fig. 13

$$\tau_5 = \frac{2 \times \text{area of smallest step}}{\text{Total flux area pro pole}}$$

The coefficient 2 has to be introduced because each pole has two pole limits.

Now we know that the area a equals always the corresponding area of a sine wave. If the angle of the area a is β we have

$$a = \int_0^\beta \sin x \, d\, x = 1 - \cos \beta$$

The total flux per pole is 2, therefore, the leakage is

$$\tau_5 = \frac{2\,(1 - \cos \beta)}{2} = 1 - \cos \beta$$

For the case under consideration the maximum leakage is obtained again for position Fig. 9; that is, for $\beta = 30$.

Fig. 13 shows the leakage coefficient τ_5 as function of the rotor position. A comparison of this curve with Curve D of Fig. 8 shows that the leakage for the light running motor is entirely different from what it is for the stationary rotor.

The maximum value of τ_5 is 0.134; that is, the same as that of τ_4, but the average value for the various rotor positions is for τ_5 only 0.046, while that of τ_4 was 0.081.

It is simple to determine τ_5 for any number of slots per pole. If n is the number of slots per pole the maximum leakage coefficient τ_5 is always:

$$\tau_5 \text{ maximum} = 1 - \cos \frac{\pi}{2\,n}$$

(equal number of slots for stator and rotor being assumed) and for the average value we find

$$\tau_5 \text{ av.} = \frac{2\,n}{\pi} \int_0^{\frac{\pi}{2n}} \tau_5 \, d\, \beta = \frac{2\,n}{\pi} \int_0^{\frac{\pi}{2n}} (1 - \cos \beta)\, d\, \beta$$

$$\tau_5 \text{ av.} = \frac{2\,n}{\pi} \cdot (\beta - \sin \beta) \int_0^{\frac{\pi}{2n}} = \underline{\underline{1 - \frac{2\,n}{\pi} \sin \frac{\pi}{2\,n}}}$$

The values as obtained from this last formula for different values of n are given in Fig. 14.

The fact that the leakage coefficient varies with the load condition makes it rather difficult to obtain an exact value for the various conditions between the no load and blocked rotor

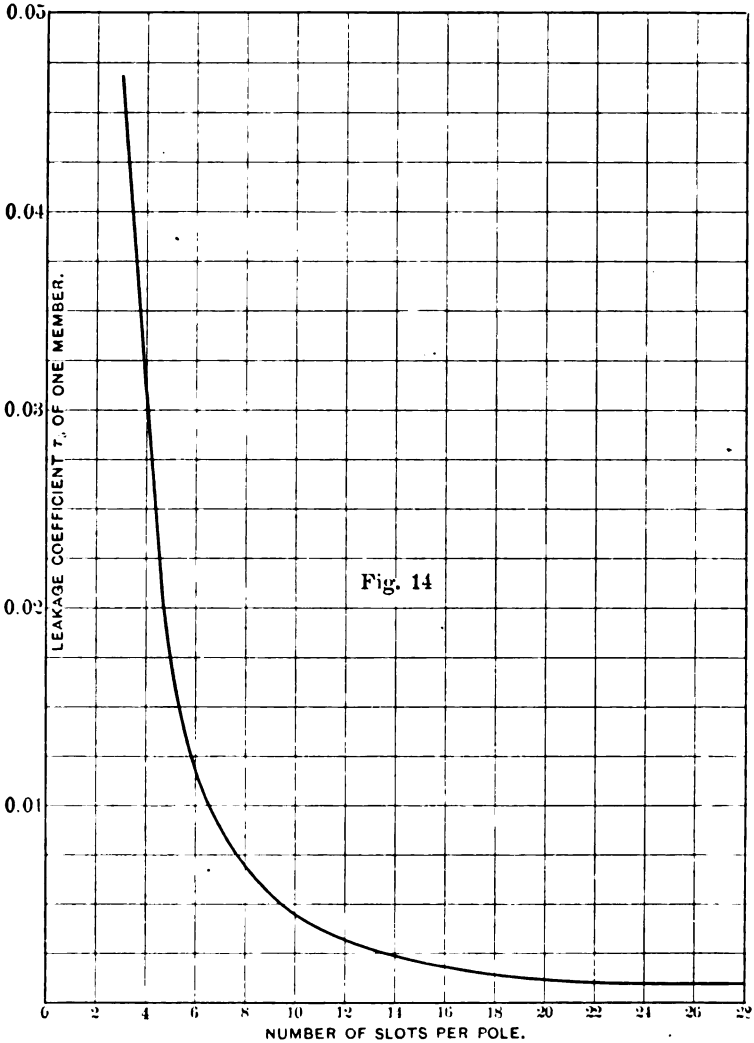

Fig. 14

conditions. The writer has shown in an article published in the *Electrical World* that the secondary reaction at the light running motor does change not only the field distribution but also the wave shape of the no load magnetizing current. It remains to be investigated how the load currents combining with the magnetizing current for the running motor are in their general character, wave shape, etc., before any final conclusions can be made. It seems reasonable, however, to assume that the right value for the leakage coefficient for the load condition will be somewhere between τ_4 and τ_5. In fact, the writer observed quite frequently that the currents for low loads have a better power-factor than found from the diagram, which is derived from the blocked rotor condition. Of course it is necessary to be very careful in concluding from tests, since the change of the leakage coefficient, caused by the fact that the reluctance of the iron is not constant, may influence the results considerably. The writer has shown in an article in the *Electrical Review*, Jan. 29, '07, that the change of the leakage coefficient caused by the changing reluctance of the iron may amount to as much as 50% between no load and blocked rotor condition in commercial motors. Since these changes tend, however, to change the leakage so as to decrease it when the motor decreases in speed, the tests showing a power-factor for low loads which is better than derived from the blocked rotor test, seem to confirm the above theories.

It may appear that the previous considerations being of a rather theoretical nature will be of little practical value, since no final formula for the zigzag leakage for the various load conditions has been given. The more surprising it will be if the writer states that this paper is the result of an attempt to give an exact and practical formula for the calculation of the leakage coefficient. This paper should, therefore, be considered more as a preliminary work, which is merely intended to bring out certain facts, which must be considered in connection with any study about the leakage coefficient.

It is obvious that in constructing a practical formula for the leakage coefficient it will be necessary on account of the rather complicated nature of the real phenomena to admit certain inexactnesses into the formula. Since this is the case it might seem advisable to use one of the existing formulas, as for instance, the one known as Behrend formula. Although this latter formula gives for motors of standard design fairly exact values, the same seems to be to the writer objectionable for two reasons. A change of the slot dimensions will, for instance, according to this formula, change the value of the leakage considerably, while in motors with a large number of slots per pole, a change of the slot dimensions does not affect the leakage very much. On the other hand, a change of the ratio of the pole-pitch to the width of core will, according to the formula, affect the leakage also considerably; while in a motor with a small number of slots per pole, said ratio has little influence on the total amount of the leakage.

Since the various kinds of leakage are not dependent upon each other, a formula for the leakage should take them into consideration separately. A formula of this kind is the latest formula given by Behn-Eschenburg. This formula, however, gives, as mentioned before, the zigzag leakage coefficient as defined by formula 3 and the values for the zigzag leakage are, therefore, considerably too large. Moreover, the dimensions of the slot are not taken into consideration at all, and the so-called belt leakage discovered by Professor Adams* is also neglected. In spite of this the latest Behn-Eschenburg formula gives also fairly exact values for the total leakage coefficient for standard motors, and the formula is fairly simple.

During several years of designing practice, the writer has become more and more convinced that the simplest formula is not at all the most practical one. In order to obtain a well-designed machine in which the best results are obtained from a certain amount of material, it is absolutely necessary for the designer to have formulas which not only give a fairly exact total result, but which also indicate in a fairly exact way the results of any change made in the design. If, for instance, the change of the slot dimensions has a noticeable influence on the performance of the motor, the designer should be able to know how much this influence amounts to. On the other hand, it seems to the writer perfectly indifferent whether the designer requires one minute or five minutes to determine the leakage coefficient of an induction motor while he is laying out a new line of machines, as long as even a small advantage may be obtained by spending five minutes instead of one. For routine design work which, of course, should be done as quickly as possible, formulas are used very little, because most factors are usually known from previous tests.

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* The writer does not want to fail to call attention to the very valuable work about the determination of the induction motor leakage, done by Professor Adams. This paper is published in the *Transactions* of the International Congress of St. Louis.

A paper presented at the 217th meeting of the American Institute of Electrical Engineers, New York, March 29, 1907.

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(*Subject to final revision for the Transactions.*)

PROTECTION AGAINST LIGHTNING, AND THE MULTI-GAP LIGHTNING ARRESTER

BY DAVID B. RUSHMORE AND D. DUBOIS

In this paper the term "lightning" is used in its comprehensive sense as defined by Dr. Steinmetz to include "All phenomena of abnormal voltage and abnormal frequency."

The object of this paper is to set forth the most recent developments in the multigap lightning arrester and to give recommendations concerning the protection of transmission lines and electrical apparatus from lightning disturbances. Reliable photographs of lightning are rare and difficult to obtain. A number of these, some of which have been published before, showing the varieties of lightning discharge, are included as a matter of general interest.

Fig. 1 is an instantaneous exposure of a stroke showing the peculiarly knotted path often taken. The best explanation of this is that the lightning at that point took a direction toward the camera, and, as is always the case, did not follow a straight line. We, of course, see the projection of its path in our direction.

Fig. 2 shows an instantaneous photograph of what is known as a meandering discharge. It is confined to the clouds and seems to be a general neutralizing of potentials.

Fig. 3 is an actual photograph of that riddle, "the thunderbolt." This phenomenon has been observed so often that we cannot deny its occurrence. There are at least three theories as to its nature.

1. That it is what it appears to be, a ball of globular lightning, which bounds about burning and destroying. This theory is backed up by no explanation.

2. That it is an optical illusion. That the eye is blinded by the light of a lightning flash and therefore sees the ball of fire wherever it looks. This theory is rational except that it does not account for the damage done where the ball is last seen.

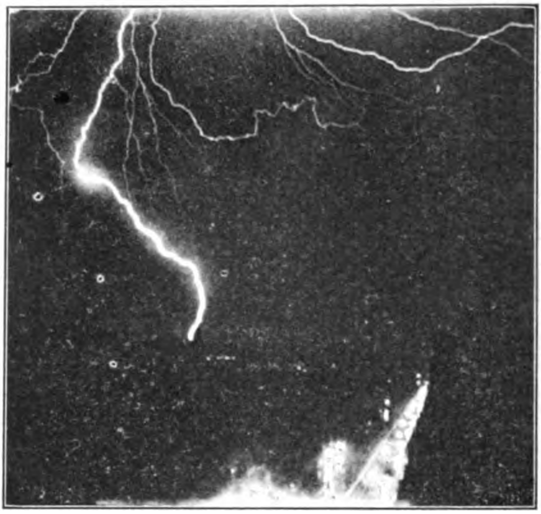

FIG. 1.

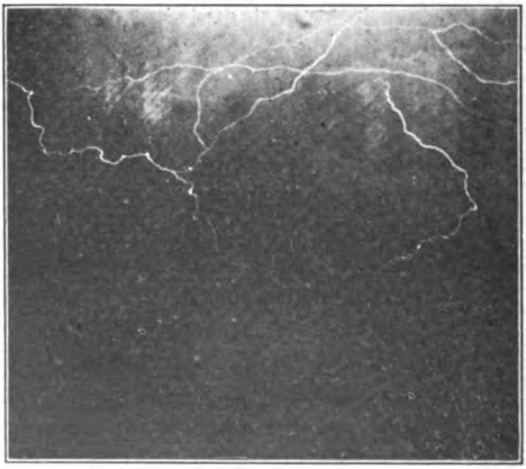

FIG. 2.

3. That the eye sees a stroke coming directly toward it from the sky, as in the knot of Fig. 1. This would produce the effect

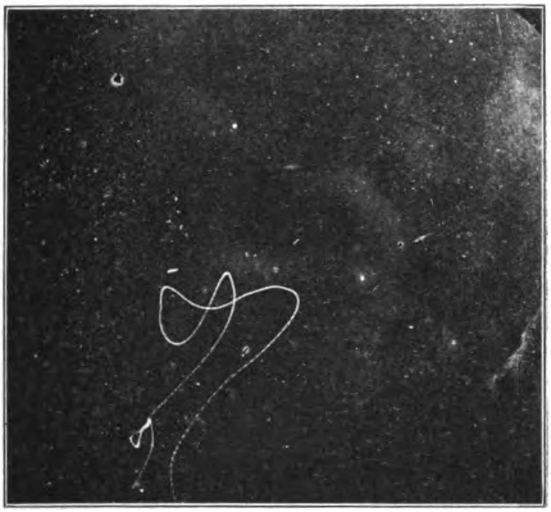

FIG. 3.

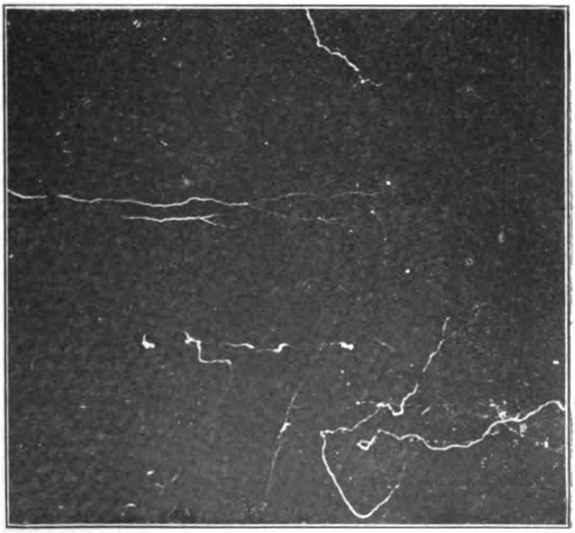

FIG. 4.

of a ball of fire, but the ball described usually moves slowly from place to place. To fit the theory, then, the lightning must be supposed to last for a considerable time and to shift its

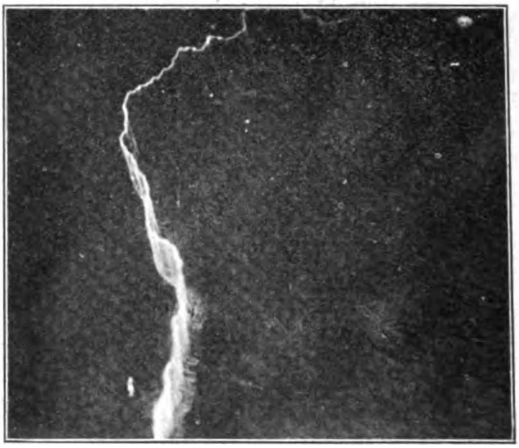

FIG. 5.

path, or to be made up of a number of strokes, each traveling by a slightly different path.

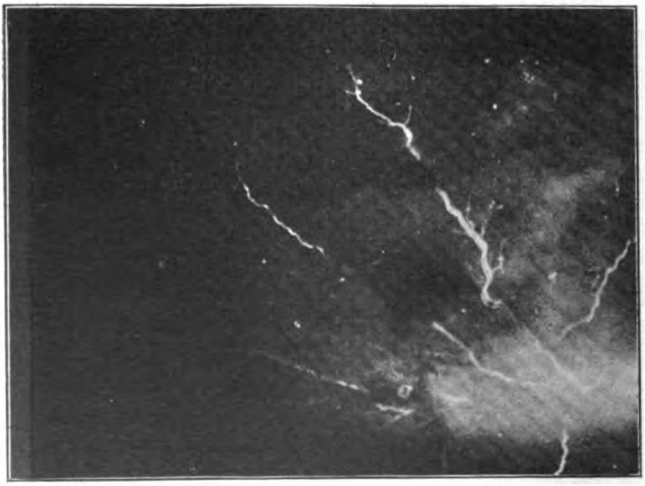

FIG. 6.

The photograph here shown should discredit the second of these theories. The dotted character of a part of a stroke should be noted.

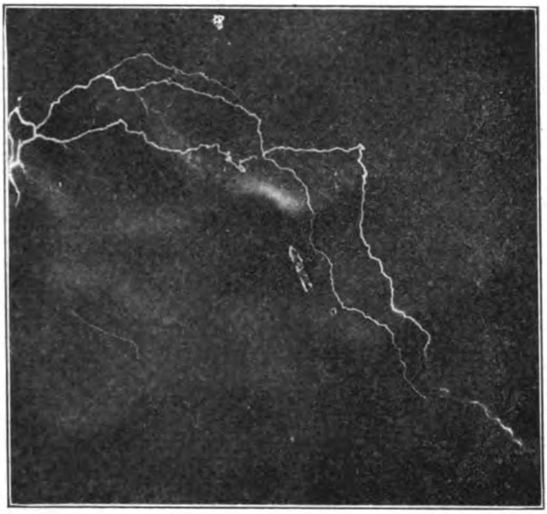

FIG. 7.

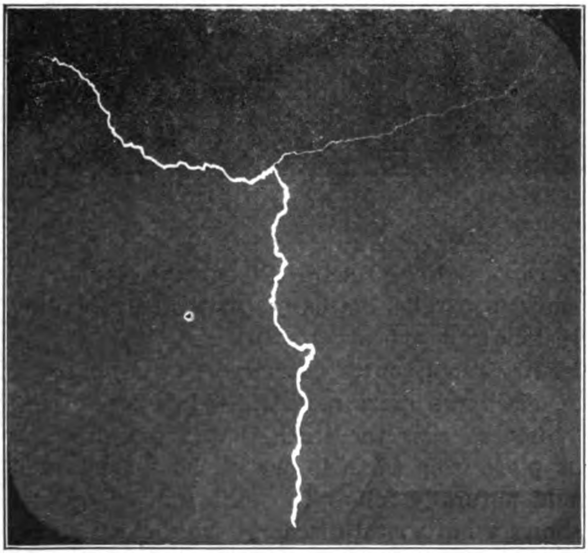

FIG. 8.

Fig. 4 shows in the lower corner another of these peculiar strokes.

Fig. 5 shows what is known as ribbon lightning. This photograph was taken from an express train on the prairie of North Dakota. This effect may not be due to the movement of a camera, as the telegraph pole shown shows no movement. It may be, however, that only the brightest part of a flash gave enough light to take the photograph of the pole. In the first case we would conclude that the stroke moves sideways. In the second case that the stroke lasted for some time. Possibly if viewed from near the point of striking this would have resembled the "thunderbolt" of Fig. 3.

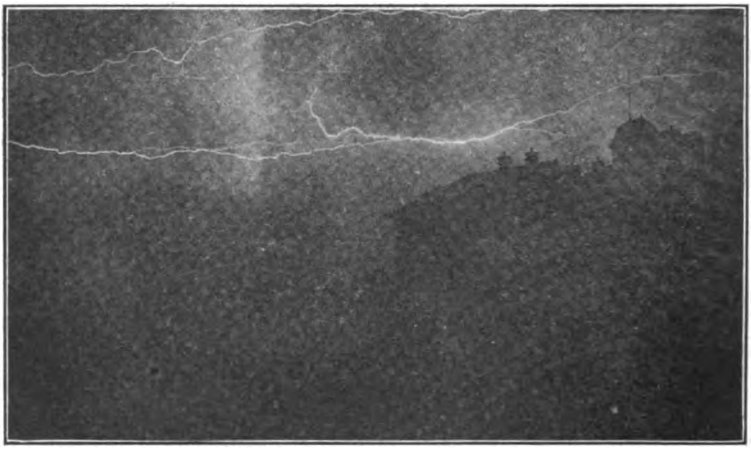

Fig. 9.

Fig. 6 shows a radial discharge among the clouds.

Fig. 7 shows a parallel discharge, most likely two discharges, one closely following the other.

Fig. 8 shows a horizontal discharge turning earthward. In this case a discharge must have started from cloud to cloud, but have come so near the earth that a second and stronger stroke took place from earth to one of the clouds. The second stroke would naturally follow the path ionized by the first.

Fig. 9 shows a horizontal discharge from cloud to cloud over Salt Lake City.

Fig. 10 is a remarkable photograph of lightning striking the tower of the City Hall in Philadelphia. This stroke knocked off one of the great iron rosettes of the tower but did no great damage.*

In considering lightning protection, the first step is naturally to study the apparatus to be protected, then the forces to which it will be subjected, and finally the protecting apparatus. The source of trouble "Lightning" is the subject of another of this evening's papers. For apparatus to be protected, we have insulators, transformers, switches and generators. The specifications for dielectric strength of generators is as provided for by the American Institute of Electrical Engineers. The usual specification for high-tension transformers is that they shall stand from line to core twice the normal line voltage, independently of whether the transformers are star or delta connected. Switches are made to stand two and one-half times normal line voltage, and insulators should stand three times the line voltage dry, and one and one-half times the line voltage

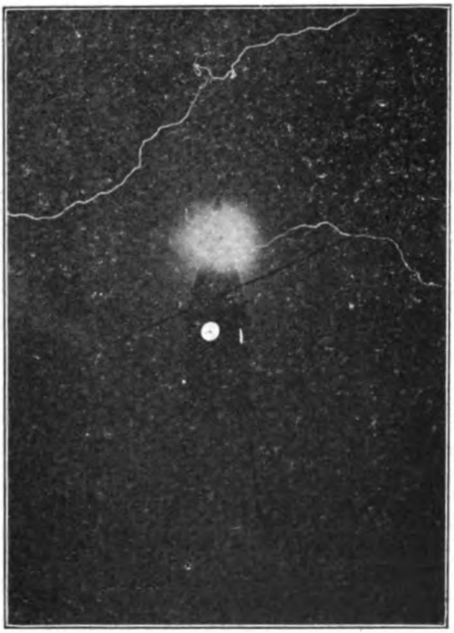

FIG. 10.

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*These photographs were obtained through the courtesy of Mr. W. F. Jennings, of Philadelphia, Pa. They are copyrighted.

with a precipitation of one-fourth inch per minute at 45°. The allowable rise of potential on the line is therefore less than 100%; about 60% of line voltage seems a desirable point at which the protective apparatus should operate.

Protecting apparatus consists briefly of lightning arresters, horn arresters, static discharges, choke-coils, and ground wires. Here lightning arresters are defined as apparatus that can relieve the line of high voltage without disturbing operating conditions.

Transformer Connections. From the standpoint of protection of the system from static disturbances, whether external or internal, the grounded star transformer connections with overhead ground wire offers the best conditions, and is in general recommended where other conditions do not decide. The causes of most frequent disturbances on transmission systems are short-circuits and grounds.

As regards short circuits between wires, there is but little to choose between the star and delta connections; but as regards grounds, and especially partial grounds, the grounded star system affords a great advantage in the reduced possibility of a disastrous increase in voltage.

When a ground is formed on one line of a high-tension transmission, that line should at once go out of operation, and with a properly designed system no interference with the delivery of power should result.

All of the considerations which enter into the question of transformer connections are not pertinent to the question of lightning protection, but from that standpoint the grounded star system with the overhead ground wire is most desirable.

The Horn Lightning Arrester. Due to its apparent simplicity, the horn lightning-arrester has of late received considerable attention. It is, however, not a piece of real protective apparatus in the sense of protecting the line without disturbing the conditions of operation. If it is used without resistance, it has the effect of a short-circuit; with resistance high enough to prevent it from causing a great drop in voltage, the protective features are largely eliminated. It is in reality an emergency device, a weak point in the system which is the first to rupture when the voltage rises to a dangerous value; if the system is without protective apparatus, it locates the point of breakdown when the condition is such that some failure must occur.

In general, the discharge of horn arresters without resistance will throw synchronous apparatus out of step, and necessitate starting up the system again. The voltage will drop to zero at a short circuit, and, as the arc may last from two to three seconds, the disturbance of the system is considerable. Where a fuse is used in series with a horn having no resistance, it can, of course, take but the one stroke and after this the system is unprotected. A flaming arc in air, such as occurs with the horn arrester, is a possible source of disturbance much worse than the original one, and under certain conditions can give rise to very high voltages, so that the possibility exists that the horn, instead of being a protective feature, may become a disturbing one.

The horn arrester with sufficient resistance to prevent short circuiting the system at time of discharge has some small protective value, which can easily be determined by the amount of resistance used. The real function of the horn arrester is its use to protect insulators along a transmission line, where the horns are so arranged that the current will jump to the horn before it will arc around the insulator. In this case the system would be disturbed either way. Where it is allowed to arc around the insulator, the latter would probably be destroyed and the time of disturbance of the system might be considerable—possibly until the insulator is replaced. With a horn protecting the insulator, the resulting short-circuit, while very undesirable in itself, is less disastrous than in the former case, and may only necessitate starting up the synchronous apparatus again.

Many disturbances caused by atmospheric lightning are of such high frequency that they will not travel along the line for any distance; but will jump to ground within a short distance of where the disturbance originates. To protect against this, the use of horns is recommended.

Care must be taken in the formation of the horns, and it must be remembered that the magnetic effect in putting out the arc is much greater than that of the heat causing the arc to rise. By improperly forming the horns, the arc will travel down instead of up, and will not clear itself. Horn lightning arresters have been installed on transmission lines in this country for a considerable number of years. In most places, however, where they have been used no careful record has been kept of their operation.

Protection for Wood Pole Transmission Lines. Practically complete protection for wood pole transmission lines can be effected against disturbances from atmospheric lightning. The best method of doing this is shown in Fig. 11. Here we have an overhead ground wire in connection with a lightning-rod and horns protecting the insulators. The overhead ground wire relieves the electrical stresses that would otherwise be thrown on the transmission line. The pipe supporting the ground wire acts as a lightning rod, and also as a horn to the top conductor,

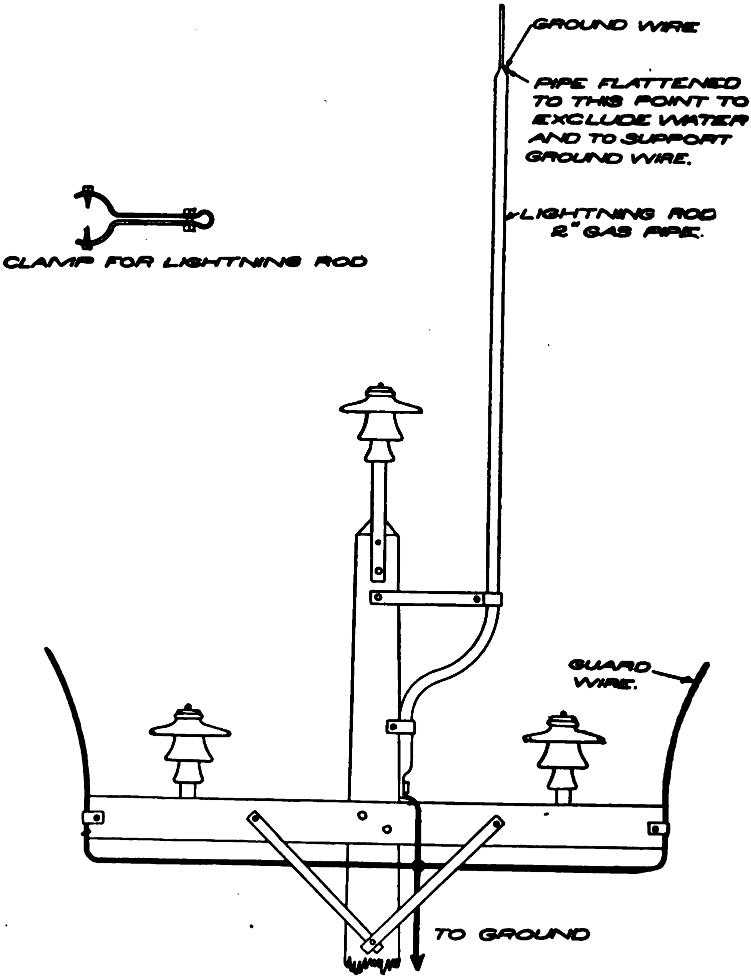

GROUND WIRE
PIPE FLATTENED TO THIS POINT TO EXCLUDE WATER AND TO SUPPORT GROUND WIRE.
LIGHTNING ROD 2" GAS PIPE.
CLAMP FOR LIGHTNING ROD
GUARD WIRE.
TO GROUND

Fig. 11.

protecting its insulator. Side horns are attached to the cross-arm, protecting the two lower insulators, and these are all well grounded by a conductor attached to the side of the pole. This sketch is somewhat diagrammatic. The actual dimensions and construction as shown would not be used. The addition of the lightning rods has in some cases been found very efficacious.

Static Discharges. From the description of the new form of multigap arrester it will be seen that the arrester includes a static discharger consisting of the high resistance with the smallest possible number of gaps in series. This should offer sufficient protection against static wherever the arrester is used. There are cases, however, where the complete arrester is not thought necessary; such, for instance, as to protect underground cable systems having no exposure to lightning. In these cases the high resistance and series cylinders can be installed alone. Of course no protection against low-frequency surges of power is obtained, and if such are likely to occur the whole of the arrester should be used.

Water-Jet Arrester. What is known as the water-jet arrester has been used abroad to some extent, and in certain localities has apparently obtained a reputation which it is difficult to justify.

The equivalent needle-gap and the resistance of this arrangement are so great that it is evident that no real protection is obtained by its use. Its only function can be that of a high resistance connected permanently to the line, and in this case it has the advantage of being self-repairing if ruptured by discharge. It should to some extent prevent the slow accumulation of static charges on the line. It is, however, difficult to install, and it is questionable if the same results cannot better be obtained in other ways. Its use is not recommended.

Ground Wire. Without doubt an overhead ground wire affords protection to a transmission line. This protection is not complete, as a very few cases exist where insulators have been lost by lightning strokes even when a ground wire was used, but these instances are so very rare that the use of a ground wire is strongly recommended. It should, however, be installed in addition to other apparatus, and, while it will almost entirely protect the line, it does not protect the station apparatus completely. The use of a ground wire very greatly relieves the stress which can be thrown on the station apparatus, however, and much reduces the duty required of the station lightning arresters.

A $\frac{3}{8}$-in. stranded steel wire, grounded at least every 500 ft., should be installed above the highest transmission wire. Experience demonstrates that this is desirable, and that a ground wire below the transmission wires or in the center of a triangle is not as effective as one above. One ground wire is all that is necessary, although theoretically more are better; but, considering the great relief obtained from one wire and the small possible margin of protection from an additional wire, which would double the cost of installation, it is doubtful if commercial considerations would often allow the installation of more than one wire. The ground wire in connection with the earth forms a short circuited secondary which helps to dampen out disturbing oscillations.

Some early experience with ground wires were with those mechanically weak, and, at least in one case, the benefits which might have been derived from the electrical protection were more than cancelled for by the frequent breaking of the wire and the trouble caused by these disturbing the transmission system. With the wires specified above, no such trouble will result.

Where a ground wire is used in connection with the grounded neutral of a star-connected high-tension system, the best results will be obtained. In some cases the ground wire is mounted on insulators and is identical with the other conductors, in which case it is possible to use it as a spare conductor after removing the grounds. In all cases, both with wooden pole transmission lines and where steel towers are used, the use of a ground wire is recommended as a protective device against the effect of lightning.

Choke-Coils. The disturbances on a system in which protective apparatus is used come from various sources and are of various characteristics as regards voltage and frequency. If our object was to protect the station against disturbances which emanate from the transmission line, high reactance might be desirable except as it interferes with the regulation of the system. When, however, the disturbance is inside the choke-coil, high reactance is undesirable. In the case of a system with large capacity, an arcing ground in series with the high-reactance choke-coil may cause excessive rise of voltage. If one goes through the list of possible disturbances, it is seen that in some cases high reactance in a choke-coil is desirable; in others it is equally undesirable. It is, therefore, recommended that a choke-coil be used, but that it possess but moderate reactance, sufficient to reduce the pressure thrown on the station apparatus by an amount which will in general bring it within the safe value of the dielectric strength of such apparatus. Moreover, a choke-coil to be effective at high-frequency discharges should have very little capacity between turns; otherwise the discharge will merely pass through from turn to turn. The coils should, therefore, not be too close together and should be insulated by a substance having low specific inductive capacity—air. Another advantage of air as an insulator for a choke-coil is that there is no chance of permanent short circuit. Where ordinary insulation is used in a choke-coil there is no way to tell that the insulation has not been destroyed. Each stroke may break down a few turns until finally the coil is punctured from end to end. At the next stroke there is trouble.

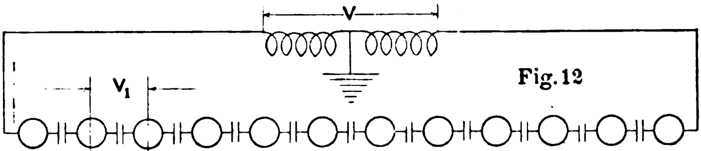


Fig. 12

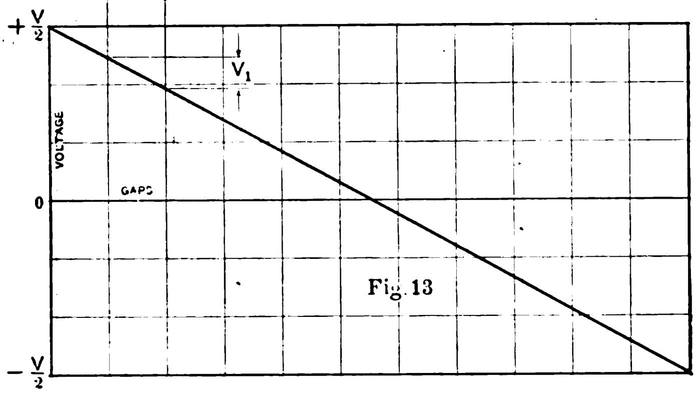
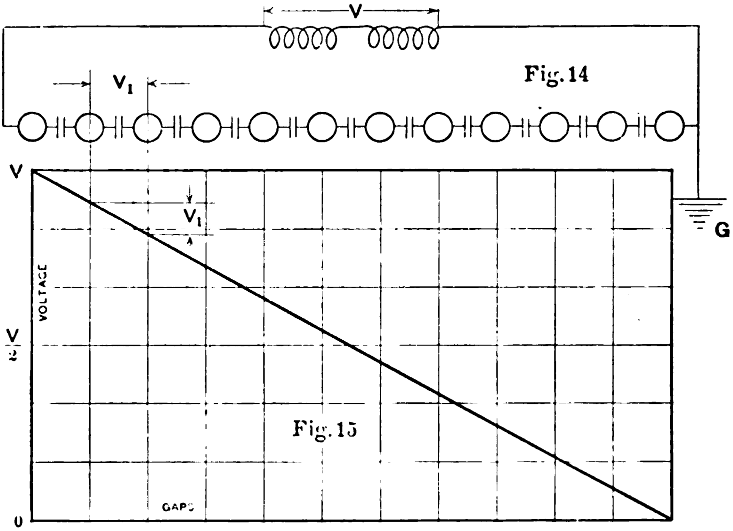


Fig. 13

Grounds. It is of the utmost importance to have lightning arresters well grounded. The ground wire, preferably flat copper strip, should lead directly to ground with as few bends as possible. It sometimes happens that a good ground cannot be conveniently made near the arrester, or that a better one can be made at a more distant point. In this case it is recommended that the principal ground be made at the more distant point, but that a ground of some sort, the best possible under the conditions, be made directly underneath the arrester. By the use of three grounds at a station the ground resistance of each can be determined. The two secondary grounds need not be complicated or expensive; iron pipes driven into the ground will answer. A record of the resistance of the grounds can thus be kept, and their good condition assured. All three should be used in parallel.



MULTIGAP LIGHTNING ARRESTER.

Theory. As is well known, the essential elements of the multigap lightning arrester consists of a number of cylinders between line and ground and line and line, these cylinders being spaced with a small air-gap between them.

The multigap arrester is distinguished from the single-gap arrester in that it can be made to discharge abnormal rises of potential without disturbing operating conditions. Under most conditions of operation, it discharges at a much lower voltage than does a single gap the length of which is equal to the sum of the small gaps, and the interrupting power is such that the disturbing charge passes off without allowing the dynamic current to follow for more than one-half cycle.

The following theory of the multigap arrangement is in part new, and is the result of very careful study of its characteristics.

As shown diagrammatically in Fig. 12, the cylinders of the multigap arrester act as plates of condensers in series. This condenser function of the multigap arrester is the essential feature in its operation.

Supposing capacity to exist between the cylinders, and no capacity between cylinders and ground; if a potential is applied across the arrester, the distribution of this potential will follow a straight-line law and the fall of potential will be the same between any two cylinders. This is shown in Fig. 13. If now we ground one end of this device, Fig. 14, the distribution of potential over the cylinders remains the same in value, but the potential is all in one direction, or the whole device is raised above zero potential, as shown in Fig. 15. However, besides the capacity between cylinders, capacity also exists between each cylinder and ground. This is shown diagrammatically in Fig. 16. The function of this second capacity is to distort the gradient.

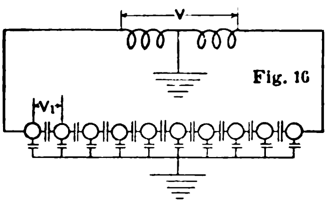


Fig. 16

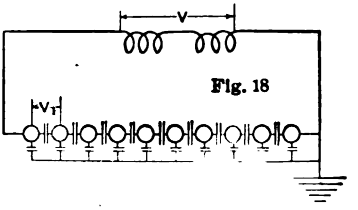


Fig. 18

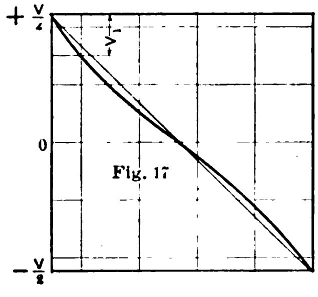


Fig. 17

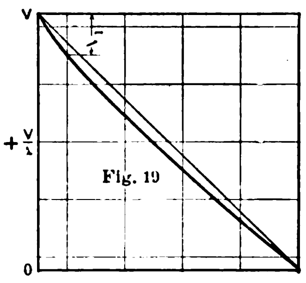


Fig. 19

Where the number of cylinders is small, the curve showing the distribution of potential does not differ greatly from a straight line, as shown in Fig. 17. It will be noticed that this is a reversed curve, being symmetrical above and below the line of zero potential.

If instead of grounding the transformer in the middle, we now ground it at one end, (Fig. 18), the whole device is raised above zero potential and the distribution of potential over the

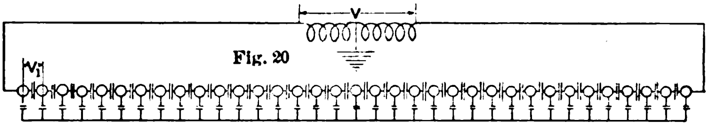


Fig. 20

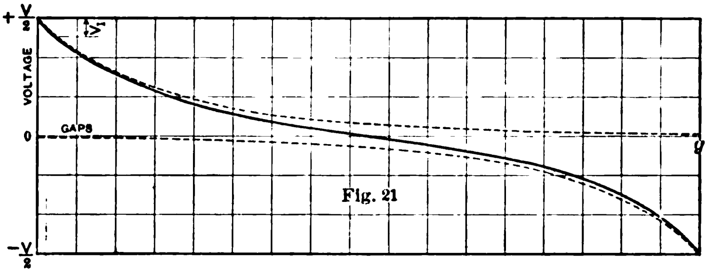


Fig. 21

POTENTIAL GRADIENT, UNGROUNDED

cylinders is as shown in Fig. 19, where the curvature is in the same direction throughout but again not differing greatly from a straight line.

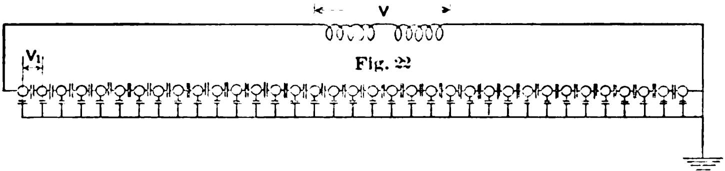


Fig. 22

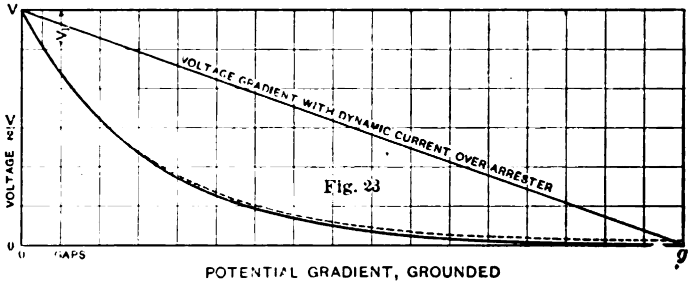


Fig. 23

POTENTIAL GRADIENT, GROUNDED

Where we have a large number of cylinders, the conditions are somewhat changed. If we have a device as shown in Fig. 20, which is supposed to represent a large number of cylinders connected across a transformer with grounded neutral, the distribution over which is shown in Fig. 21, it will be noted that this curve differs considerably from a straight line. In this case there is a part of the apparatus in the middle where very small difference of potential exists between the cylinders, and the fall of potential at the end cylinders is much greater than that which exists between the cylinders nearer the middle. The distribution of potential over the device exhibits the general form of combination of an exponential function of opposite sign. If one end of the transformer is grounded instead of the middle, as shown in Fig. 22, we have the distribution of potential shown in Fig. 23. It will be noted that the drop of potential over the end cylinders, as shown in V_1, Fig. 23, is very much greater than that shown in V_1, Fig. 21, the voltages between lines being the same. If this potential drop reaches a certain value, a discharge across the cylinders takes place. With a large number of cylinders, therefore, a voltage which could not break through when the system was grounded in the middle may be high enough to break through when one end is grounded.

It will be seen that the potential between the first and second cylinders in Fig. 23 is much greater than between the second and third, etc., from which it is evident that this arrester breaks down in successive steps. At a certain voltage across the arrester the potential gradient between the first and second cylinders is sufficient to break down the dielectric between them. The potential of the second cylinder, then, being connected to the first by an arc, rises, and may rise to such a point that it breaks down to the third cylinder, and the third to the fourth, and so on till the arc has passed entirely across the arrester; then the line current starts flowing across and the distribution of potential is changed, following now a straight line as shown. The potential difference between all cylinders is then the same, and becomes much less than in the case before a breakdown. It is well known that to maintain an arc of alternating current across a gap, the voltage must be at least high enough to re-break down the dielectric each time after the arc goes out at the end of a half-cycle. The dielectric is greatly weakened by the heat produced by the passage of the arc, therefore the voltage to maintain the arc need not be as high as that which originally broke across. The weakening of the dielectric depends on the heat of the arc, and as this depends in turn upon the boiling temperature of the metal of the arc cathode, certain metals when used as electrodes require a higher voltage than others to maintain an alternating-current arc. The connection between the boiling point of the electrode metal and temperature of the arc is as follows: the current is carried across the gap by a stream of metal vapor coming from the cathode. If the metal vapor forms at a low temperature, the temperature of the arc will be low. Unfortunately, the low boiling temperature metals do not hold their form well under the electric arc. It is, therefore, necessary to use alloys rich in these metals. The metals of higher boiling point can not vaporize while those of lower boiling point are present, and so hold the cylinders in form without effecting the temperature of the arc. In the actual lightning arrester, much depends upon the choice of this alloy for the cylinders.

The arresters are, of course, designed so that the voltage gradient shown by the straight line in Fig. 23 is not steep enough to give a voltage across the gaps high enough to maintain an alternating-current arc. An arc following a discharge across the arrester would therefore go out at the end of the half-cycle in which it occurred.

In connection with the physical phenomena which takes place when the dielectric breaks down between cylinders, a note on the characteristics of air as a conductor of electricity is of interest.

Gases in general are such poor conductors of electricity that for long there was discussion pro and con regarding their possession of this property. A very small conductivity, however, exists under normal conditions, and this may be much increased in a number of ways, so that gases under certain conditions are good conductors of electricity. The gases conduct electricity when the temperature is raised above a certain point; when the gas is drawn from contact with incandescent metals or carbon, or is drawn from the vicinity of flames; when an electric charge has passed through the gas, or when röntgen, lenard, or cathode rays have passed through the gas; also when rays from radioactive substances or from uranium or thorium have passed through it; when gas has been exposed to rays from electric sparks; when the cathode is illuminated by ultra-violet light; also when air has passed over phosphorus or bubbled through water. Thus it is seen there are many means of imparting electric conductivity to gases, and not a few of these are concerned in the breakdown of the multigap arrester.

When gas has become ionized by an electric discharge or otherwise, it retains its conductivity for a period which may vary from five to eight minutes, more or less, a fact which has an important bearing on discharges which follow the first breakdown, and also a fact to be taken into consideration in the use of fuses and circuit-breakers.

The partial breakdown of a lightning arrester under normal conditions, when the static spark is playing across the first few gaps, generates rays which assist the breakdown of the gaps exposed to them; and as the breakdown of the arrester is a process of successive steps, the cumulative influence of this action may be considerable. The first discharge which passes across the dielectric or air is a true conduction of electricity by the gas. The succeeding strokes, however, are more or less in the nature of a minute arc stream, as shown by the spectroscope.

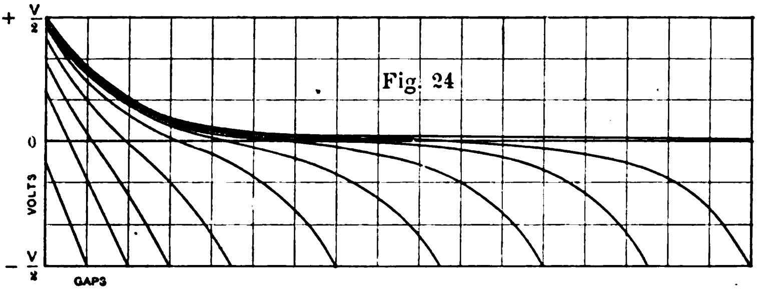


Fig. 24

POTENTIAL GRADIENTS UNGROUNDED

As before stated, when the voltage between any two cylinders becomes high enough, an arc takes place between them. Also voltage is highest between the cylinders nearest the line. Fig. 24 represents a series of potential gradient curves, with number of gaps and voltage just sufficient to start the discharge across the first gap. These curves are for the ungrounded case and follow the approximate equation:

$$V_x = \frac{V}{2} (K^{-x} - K^{x-g})$$

where V_x is the voltage at any point x,

V is the voltage across any arrester,
g the gaps of the arrester, and
K a constant depending on the ratio between the capacities of cylinder to cylinder, and cylinder to ground. In all these the potential gradient between the end cylinders is seen to be the same and is supposed to be steep enough to break down the dielectric. It is seen that the number of useful gaps is limited, that beyond a certain point it makes no difference how many gaps are added, the voltage of breakdown is not raised, and that there is a definite limiting voltage which would start a spark across the first of an infinite number of gaps. As has been often pointed out, a lightning stroke itself must be a phenomenon something of this nature, as the distances are so great that we cannot conceive of voltage high enough simultaneously to rupture the entire dielectric. The lightning must either break from drop to drop or from dust particle to dust particle, working its way across to its destination.

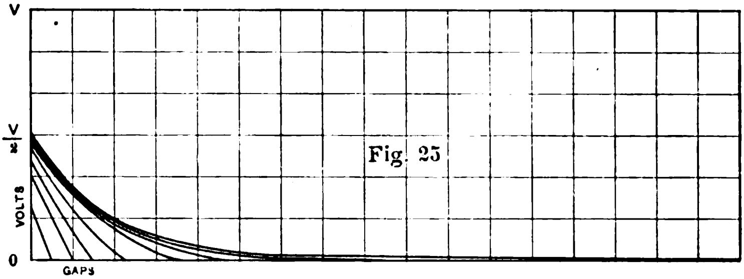


Fig. 25

POTENTIAL GRADIENTS GROUNDED

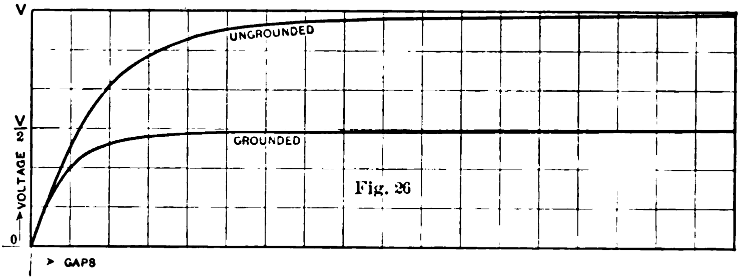


Fig. 26

Fig. 25 shows the condition with one line grounded. In this case the potential gradient between the first and second cylinders is the same as before. It is seen that both the number of useful gaps and the limiting voltage are half what they were before, for where the number of cylinders is such that the curve of distribution of potential becomes tangent to the axis of zero potential, any increase in the number of cylinders does not increase the voltage at which they break down, and this is just half the limiting curve for the ungrounded condition. In the design of the practical lightning arrester, however, we do not

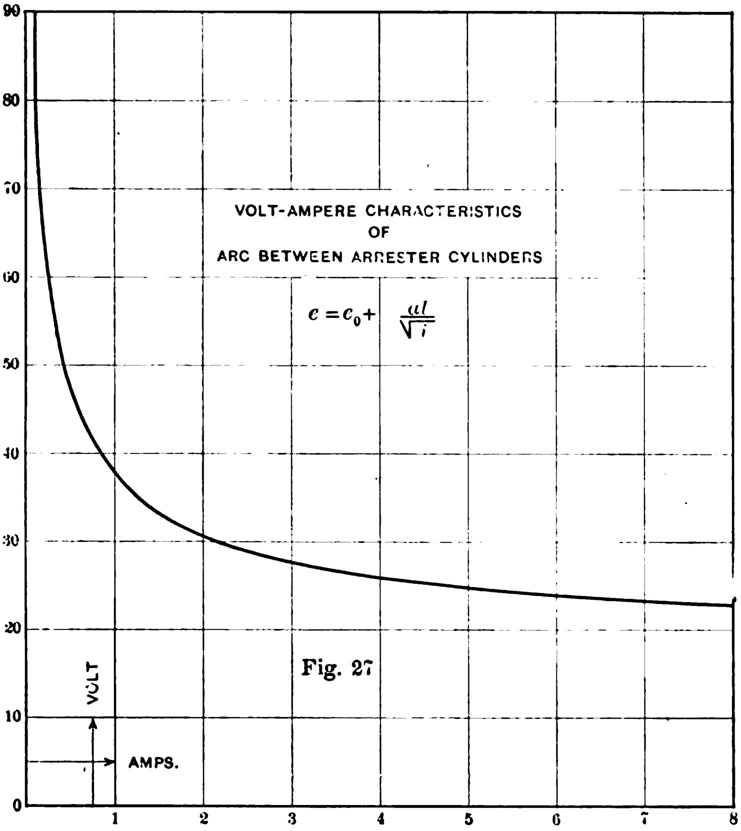


Fig. 27

work so high on the curves as is here shown, and the curves themselves are altered by the use of resistance. It is to be noted that for a low number of gaps there is little difference between the grounded and ungrounded curves.

Fig. 26 shows curves of voltage and number of gaps founded on the curves of Figs. 24 and 25. These curves are of the same shape as have actually been found by test.

Fig. 27 shows the volt-ampere characteristic of the arcs between cylinders, and indicates that the voltage between cylinders is equal to the counter electromotive force of the arc plus a factor which is approximately inversely proportional to the square of the current.

Fig. 28 shows the distribution of potential over the arrester with one line grounded, where breakdown occurs over a number of gaps without a complete discharge. This is one of the phenomena of multigaps. It will be noted that the potential gradient between the first two cylinders begins in this case at a point greater than the spark voltage, and that when this gap breaks down a new gradient is then established from cylinder No. 2, which, although not so steep as that from No. 1, still breaks down the gap to No. 3; thus the successive gaps break down until a gradient is reached less than the spark voltage. The reason for the decrease in gradient is as follows:

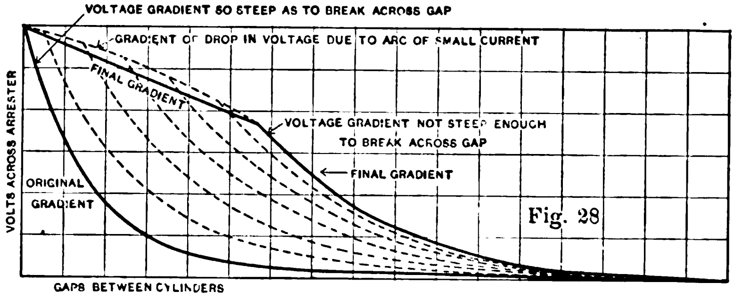


Fig. 28

when breakdown occurs from one cylinder to another, the second cylinder is charged to the potential of the first, less the drop in voltage due to the arc, which is shown in the arc characteristics, Fig. 27, to be very great at small currents. The current which flows across the gaps in this arc is, of course, small. It is made up at the normal frequency charging current and the charging current necessary to raise the gradient to its new position. On low frequency this last is most important. Due to the drop in voltage as the successive cylinders break down, the current through the arcing gaps also decreases, the gradient of drop in voltage following a curve. If the potential gradient as the arrester breaks down from one cylinder to another does not reach a value less than that of the spark voltage, the breakdown of the arrester is complete and discharge passes entirely across the apparatus. This means that either the voltage was higher at the start than in Fig. 28, or that the drop in voltage between the gaps was less. This is shown clearly in Figs. 29 and 30, which also indicate in the most interesting manner the difference due to the effect of frequency, which is a very important factor with the multigap lightning arrester.

In Fig. 29 the voltage was higher than in Fig. 28 and the discharge was therefore complete. Fig. 30 with the same voltage as in Fig. 28 shows the effect of high frequency.

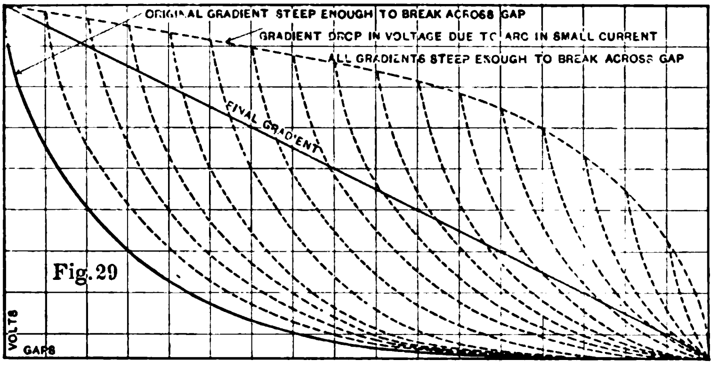

ORIGINAL GRADIENT STEEP ENOUGH TO BREAK ACROSS GAP
GRADIENT DROP IN VOLTAGE DUE TO ARC IN SMALL CURRENT
ALL GRADIENTS STEEP ENOUGH TO BREAK ACROSS GAP
FINAL GRADIENT
VOLTS
GAPS

Fig. 29

COMPLETE BREAKDOWN LOW FREQUENCY

As stated above, when the breakdown occurs from the first to the second cylinders, the potential of the second cylinder depends upon the amount of current which passes. As this current is that due to the capacities, which have been considered, it will be greater at high frequencies and the fall of potential between the first and second cylinders will therefore be less. As the arrester gaps break down successively, the fall of potential from one cylinder to another is less, and therefore such an arrester will discharge at a lower voltage for a higher frequency

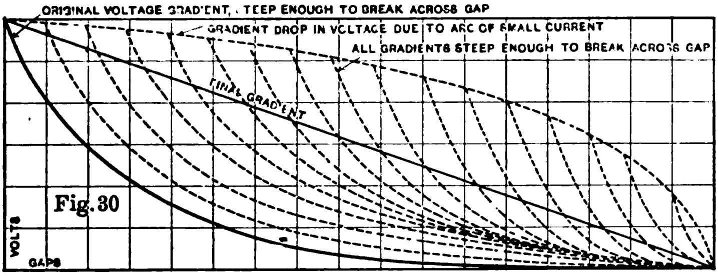

ORIGINAL VOLTAGE GRADIENT, STEEP ENOUGH TO BREAK ACROSS GAP
GRADIENT DROP IN VOLTAGE DUE TO ARC OF SMALL CURRENT
ALL GRADIENTS STEEP ENOUGH TO BREAK ACROSS GAP
FINAL GRADIENT
VOLTS
GAPS

Fig. 30

COMPLETE BREAKDOWN HIGH FREQUENCY

than for a low. At high frequency, due to the inductance of the cylinders themselves, the normal gradient is steepened; this also assists breakdown. In such cases (Figs. 29 and 30) where the arrester discharges completely, no point is reached where the potential gradient is less than that of the spark voltage.

As is well known, the multigap arrester without resistance discharges more easily at high frequencies than at low. By properly designing the resistance, this can in a large measure be overcome, so that the arrester will protect equally well at one frequency as at another. However, in the case under consideration, no resistance was assumed.

In the same way that high frequency lowers the breakdown of multigaps by increasing the current of the spark, high resistance, by absorbing voltage when this current flows, decreases breakdown. Resistance is more effective at high frequency in increasing breakdown voltage, as at high frequency the charging current is higher and therefore there is more voltage drop in the resistance.

Resistance. Resistance is one of the important factors of lightning-arrester construction. Its usual functions are, in general 1, to limit the current. 2, by shunting part of the arrester to give fewer gaps for low frequency to break across.

Series resistance limits the current under all conditions, but, although in this way protecting the arrester, it is dangerous in case of a surge. It has still another and perhaps worse effect. All resistance is more or less inductive, and in case of high-frequency stroke, serious resistance will prevent free discharge and tend to reflect the disturbing wave. With series resistance the arrester may have all the optical appearance of discharging freely and may puncture test papers, while its real value as a protecting device is not indicated in any way.

The discharge of any quantity of electricity from a good resistance during a time which must be at a maximum but a half-cycle is easily a matter of calculation, and it is apparent that, other things being equal, the protection afforded by an arrester is inversely as the amount of series resistance.

As will be described below, an arrester has been developed in which no series resistance has been used, but in which resistance nevertheless limits the current of discharge except in extreme cases of surge. Resistance also makes the arrester break down at uniform voltage at all frequencies and assists to discharge surges.

The desirable characteristics of resistance are as follows, it being impossible to obtain them all in any one known combination:

1. Sufficient heat-absorbing capacity.
2. Surface of such character that arc will not flash over·
3. Must be easily replaceable.
4. Non-absorptive as regards moisture.
5. Uniform conductivity over section.
6. Non-inductive and straight.
7. Should have no coherer action.
8. Sufficient mechanical strength to stand red heat without failing.
9. High specific resistance.
10. Resistance should not change with use.
11. Must not become incandescent under service conditions.
12. Must allow of good contacts.

Ideal Lightning Arrester. The ideal lightning arrester should prevent any rise of voltage dangerous to insulation. It should offer a free path of discharge from line to ground and from line to line, and should preform its functions without disturbing the operation of the system. It should put out the arc at the end of the half-cycle in which it starts, and should have no discrimination in its protective power as regards the frequency of the disturbance. That is, it should discharge at a certain voltage for any frequency. An arrangement of gaps and resistance as shown in Fig. 31 meets this last condition in this way; gaps alone break down more easily at high frequencies, but high frequencies will not readily break down through both resistance and gaps. Low frequency is not impeded as much by resistance, but can break through only a few gaps for the same voltage compared with high frequency. For a given voltage, then, the higher frequencies would break through the path with gaps only; frequencies somewhat lower, through the path with moderate resistance; and low frequency and accumulated static through the path with the high resistance. An arrester of this type, however, possesses the disadvantage that after a voltage of low frequency breaks across the gaps in series with the high resistance, the current which can follow cannot relieve the line. This can be overcome by an arrangement such as shown in Fig. 32. In this case the same paths of breakdown for the different frequencies are retained, but now if low-frequency breaks down the gaps in series with the high resistance, the entire voltage less that consumed in the arcing gaps is concentrated across the next highest division of gaps. These, if correctly designed, will at once break down, passing the strain still farther up the arrester, and so on, the arrester breaking down in sections until it is either completely broken down or the line voltage has been lowered by the current flowing through the resistance. This idea has been worked out in the design of a new line of arresters described below.

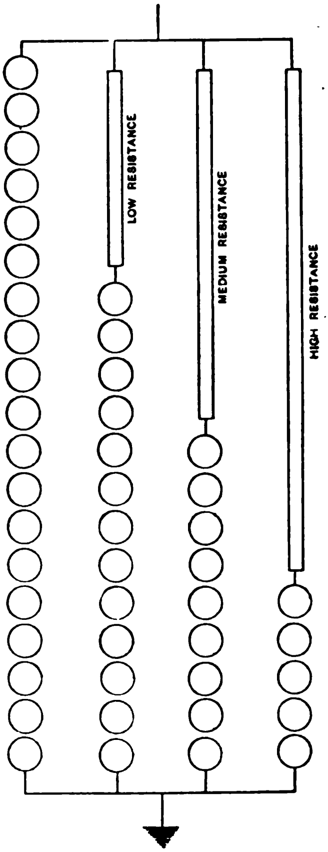


FIG. 31

The Graded Resistance Lightning Arrester

During the last year a very large amount of experimental work has been done to develop the multigap arrester, and it is felt that the results obtained will be, so far as can now be seen the maximum development of this type of apparatus.

The multigap lightning arrester has had the property of responding more readily to high frequencies than to low. In the new designs, however, by the use of resistance, as just described, this has been, so that a low frequency now discharges with the same facility as high frequency, and the discrimination with regard to that condition is largely removed.

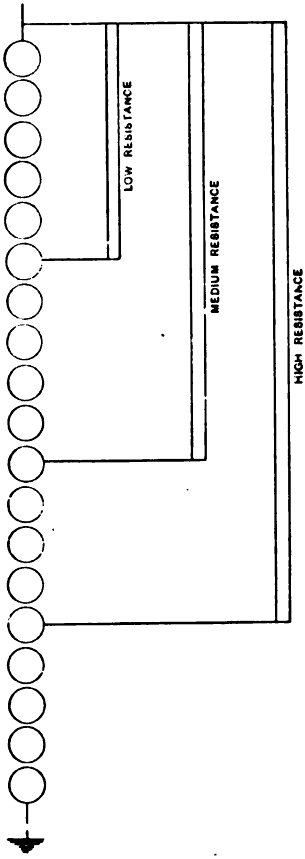


FIG. 32

The arrangement for these arresters for 35,000 volts is shown in Fig. 33 for the delta and ungrounded star transformer connections, and Fig. 34 for grounded star systems. In each case we have three legs made up of *V* form multigap units, Fig.

35. Each leg is connected to one of the lines through a spark gap shunted by a fuse. Connected in just below the fuse we have a novel device, in that we have the three resistances in parallel, tapping in to different parts of the leg as shown. These three line legs are joined at their lower ends by a common or

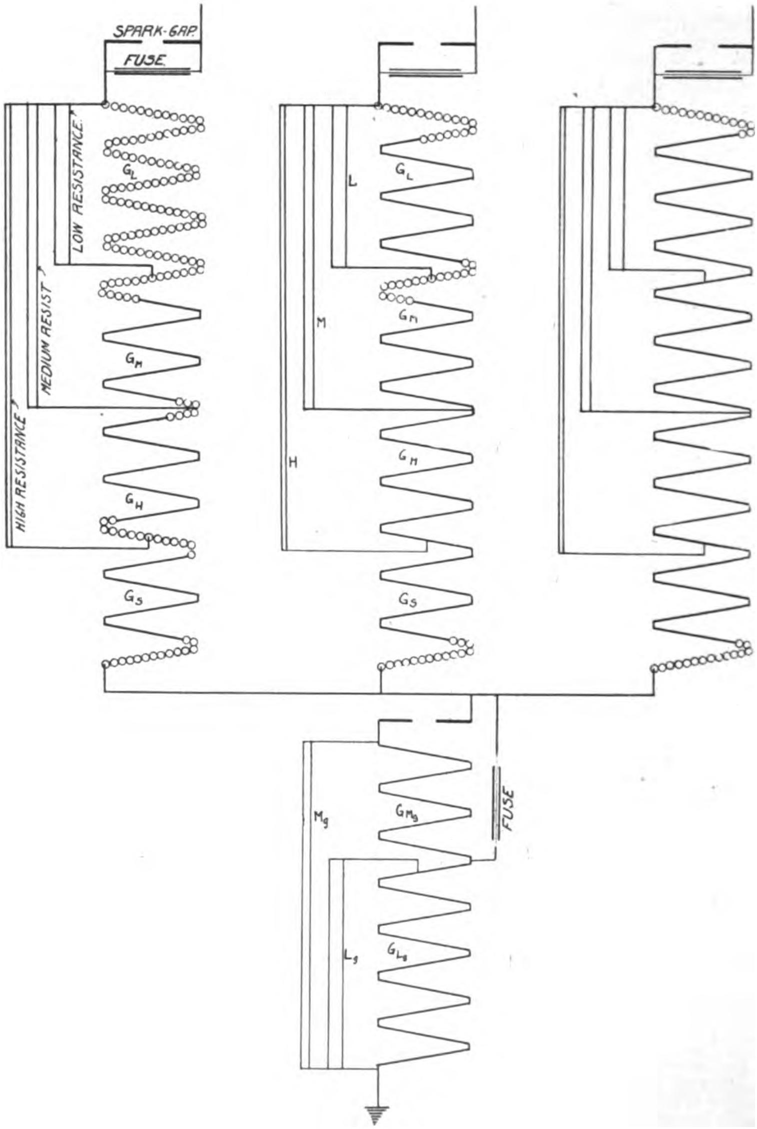


Fig. 33.

multiplex connection, from which, for ungrounded systems, a fourth leg connects to the ground. In the arrester for grounded star systems no fourth leg is added, the multiplex connection being connected to ground.

Fuses. The use of a fuse in shunt with the spark-gap is for the condition of continuous high voltage on the lines from any cause, an arcing ground or otherwise. The fuse will then blow

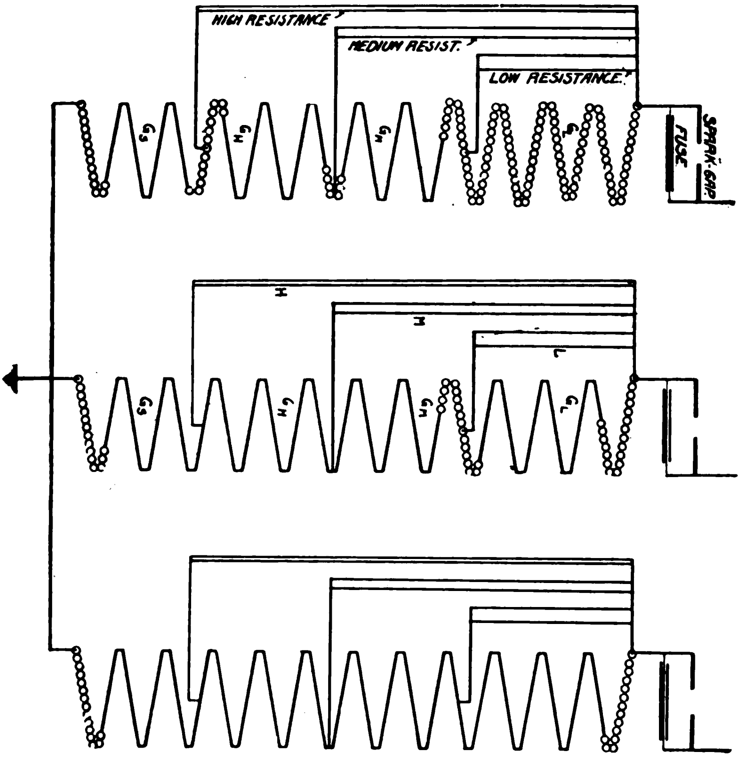


Fig. 34.

and it will throw the gap in series with the arrester and thus bring about an automatic adjustment of the gaps. This allows the arrester to be adjusted to discharge at but a small percentage above the line voltage, and thus to afford real protection. The introduction of the extra gap does not destroy the arrester as a protective device; it merely adds a factor of safety against the destruction of the arrester. If this fused gap were omitted, its equivalent would have to be introduced as additional multigaps. This fuse is so proportioned that it will not blow at an ordinary discharge. The small complication of the addition of this device is much more than offset by the close adjustment possible in the arrester, thus allowing the best protection to be had.

Resistances. The three resistances, designated respectively L, M, and H for low, medium, and high, represent a distinct advance in the art of lightning-arrester design.

The operation of these resistances has been partly described above. It has been shown how they force discharges of different frequencies to select different paths, giving breakdown at about the same voltage in each case; also how they assist in the breakdown of the arrester to give full discharge in case of surge. It should be noticed that the gaps G_1, which would be the last to go down in this way, are of greater number than the other divisions, as it is not desirable that these gaps should breakdown except under extreme conditions. The low resistance, L, should be able to discharge the line sufficiently to relieve the voltage. It must be clearly understood that the use of the word "breakdown" means the discharge, not the failure of the arrester. It has been found that when gaps are shunted by resistance and the resistance is low enough, dynamic current will not follow a high frequency across those gaps, but will shunt at once to the resistance. Such a relation exists between the gaps G_1 and the resistance L. This being the case, it is seen that the resistance L is practically a series resistance so far as the

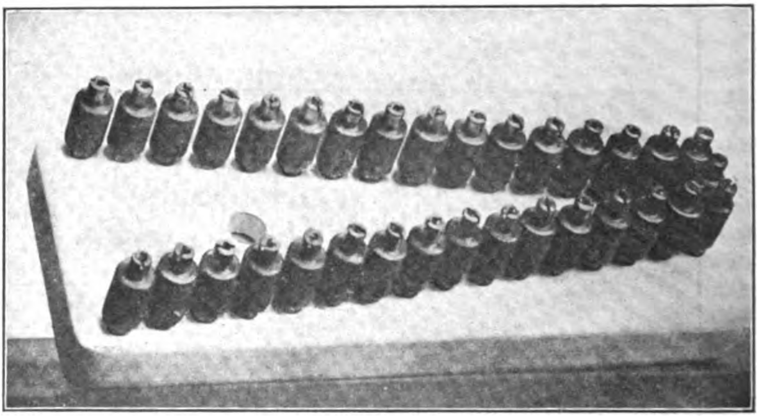


FIG. 35.

safety of the arrester is concerned, but that it introduces neither of the objectionable features mentioned above. High frequency discharges do not have to pass through it, and the shunted gaps can arc over in case of necessity.

Another point to be brought out is that when gaps in series with resistance, such as L and G_m, are shunted by a second resistance such as M, a certain relation will bring about a condition such that a discharge of high frequency down the arrester will be followed by dynamic shunted through M instead of through L and G_m. M may be in this arrangement many times L in resistance, and in the arresters is high enough to limit the current which follows a stroke so as to give very little burning of the cylinders.

The resistance H, as has been explained, is used for assisting the breakdown of the arrester, and is also used as a static discharger, to allow small currents to leak to ground and thus prevent any accumulation of electricity on the line.

The arresters of this type are so designed that, should the arc pass across all of the gaps following the static discharge, the number of gaps is sufficient to extinguish the arc, and this holds with each resistance and with the gaps connected with it. That is, any current which might start across any of the resistances and the corresponding gaps would immediately be extinguished by that combination alone without the shunting effect of the other resistances, thus rendering the extinguishing of the arc doubly secure.

The breakdown of the gaps does not follow a straight-line law as regards voltage and number of gaps, the increase in voltage being less than proportional to the increase in the number of gaps. This is the reason why, with a grounded star system, no fourth leg is used in the arrester connection to ground, although we have in reality the multiplex connection between line and line. In this arrester the same margin for breakdown exists between line and line as between line and ground, but twice the number of gaps in series do not require twice the voltage to break over them, but with these proportions, approximately the voltage multiplied by $\sqrt{3}$.

With regard to the grounded leg, the fuse is so connected with the L_g resistance that but few gaps are in series, and we have a sensitive condition where the arrester will discharge easily at low as well as high frequencies. When, however, the fuse in the grounded leg blows, due to a ground on the line, we still have an arrester which will protect the line with one phase grounded, without suffering any injury to itself.

Lightning arresters of the form shown in Figs. 33 and 34 have been designed for the following voltages: 6,600, 10,000, 12,500, 15,000, 20,000, 25,000, 30,000, 35,000, 40,000, 45,000, 50,000, and 60,000 volts. Anything between these voltages is, of course, taken care of by the arrester on one side or the other, as is thought best. For lower voltages, down to 300 volts, the arresters are of slightly different design, having only two resistance rods. The 2300-volt arrester is shown in Fig. 36. For voltages below 300 volts no resistance is necessary, as the voltage is so low that the arc can never hold. These arresters, therefore, consist simply of single spark-gaps to be connected directly across the line.

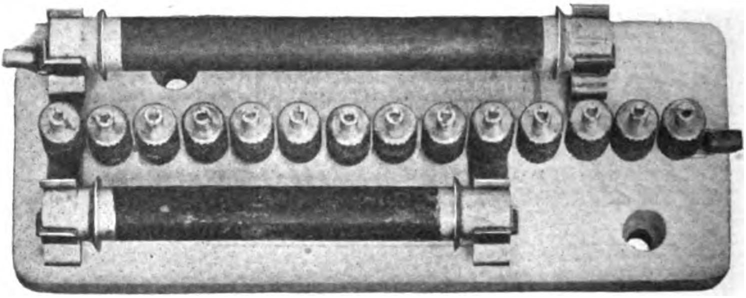


Fig. 36.

The 2300-volt arrester, Fig. 36, being intended for pole as well as station use, is necessarily simpler in design than the high-voltage arresters. It consists of 14 cylinders, 9 of which are shunted by a low resistance and 11 by a high resistance. As in the case of the higher voltage arresters, the grading of resistance makes this arrester discriminate between frequencies, giving each a path to break down that requires a voltage not too high or too low. Accumulated static passes off across the high resistance and two gaps in series. High-frequency discharges pass across the entire arrester; moderate high frequencies across the low resistance and four gaps. The low resistance is, as in the other arresters, proportioned with the number of shunted gaps so that the high-frequency discharge across these gaps is never followed by the dynamic current, the dynamic shunting at once to the low resistance. A photograph of this arrester discharging is shown in Fig. 37. Note that a discharge takes place over all the gaps, but that the arcs between the gaps shunted by the low resistances are very small compared with the bright arcs between the last four gaps. The static discharge is passing through all the gaps, while the half wave of dynamic current following the static is shunted part of the way by the resistance.

Fig. 38 shows an oscillogram of this phenomenon. It is seen that the only current in the shunted gaps is the current of static discharge. It should be noted that the current shown is not a measure of the true current, as the oscillograph can not respond to currents of such high frequency.

Fig. 39 shows an interesting oscillogram. Here both the total number of gaps and the shunted gaps were reduced to a point considerably below the safe limit. The static discharge was at once followed by a half cycle of short-circuit current across all the gaps, voltage falling almost to zero. The following half-cycle, however, shows that the current left the shunted gaps and flowed through the resistance, extinguishing entirely after the end of this half-cycle. With the small number of gaps used, if it had not been for the resistance the arc would have undoubtedly and the arrester would have been destroyed. This merely held shows the protection offered by a shunt resistance a step below that designed. In a correct design, the dynamic could not have started across the shunted gap in this way, and the total number of gaps is sufficient to extinguish the arc of short circuit,

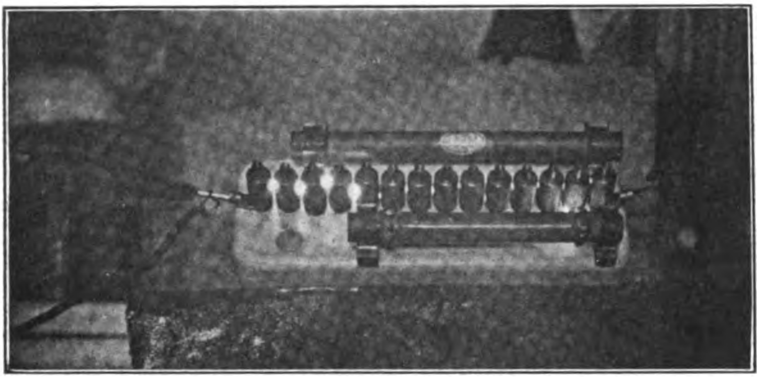


Fig. 37.

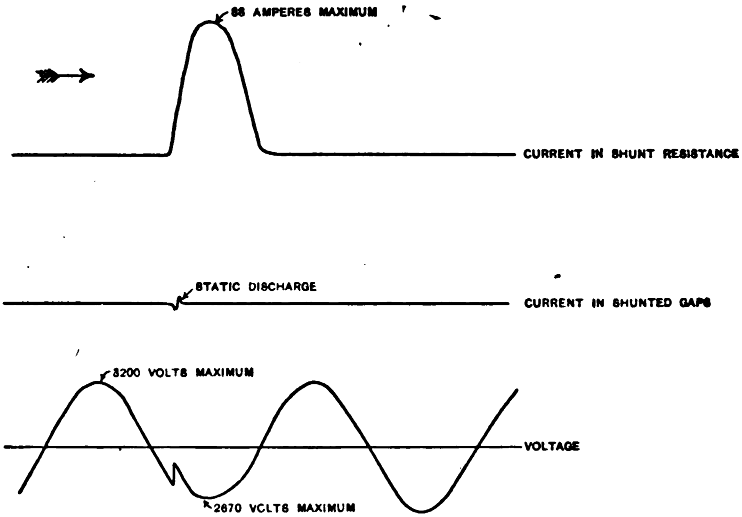

88 AMPERES MAXIMUM
CURRENT IN SHUNT RESISTANCE
STATIC DISCHARGE
CURRENT IN SHUNTED GAPS
3200 VOLTS MAXIMUM
VOLTAGE
2670 VOLTS MAXIMUM

FIG. 38

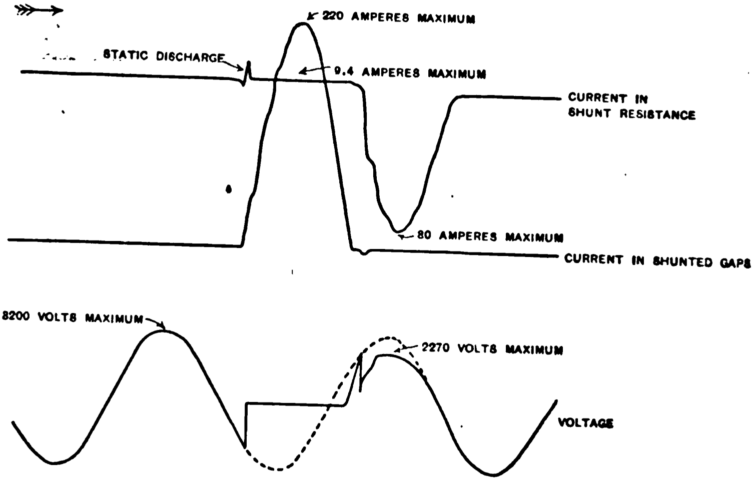

220 AMPERES MAXIMUM
STATIC DISCHARGE
9.4 AMPERES MAXIMUM
CURRENT IN SHUNT RESISTANCE
80 AMPERES MAXIMUM
CURRENT IN SHUNTED GAPS
8200 VOLTS MAXIMUM
2270 VOLTS MAXIMUM
VOLTAGE

FIG. 39

even with no resistance. Returning to the low-frequency breakdown; as before stated, accumulating static merely discharges over the two end gaps. For a rise in generated voltage or a power surge, however, the current which could discharge through the high resistance would have no protecting effect. But with these two gaps broken down and arcing across, the high voltage would be concentrated across the next two gaps. As practically the same voltage broke through the first two, these will at once break down, allowing a discharge through the low resistance which should be able to take care of the system. To sum up, the effect of this use of resistance is as follows: the high resistance discharges static at low voltage and assists breakdown in case of surge. The low resistance allows low breakdown in case of surge, gives correct breakdown to medium high frequencies, reduces the burning of the cylinders and in that way gives the arrester longer life, and prevents any disturbance of the system which might result from a half-wave of short-circuit to ground.

This arrester is designed to operate across 2300 volts. It is used, however, from each line to ground, it giving in that way sufficient protection and being always able to handle a discharge when one line is grounded. It is built to be used single-pole, but by placing two or three in the same box, becomes double-pole or triple-pole.

On grounded systems this arrester can be used up to 4,000 volts between lines. On ungrounded systems by using two arresters line to line and one from the middle to the ground, this arrester can be used up to 4,000 volts.

The 1000-volt arrester is nearly the same in design but has only one series gap below the high-resistance rod.

A paper presented at the 217th Meeting of the American Institute of Electrical Engineers. New York March 29, 1907.

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NEW PRINCIPLES IN THE DESIGN OF LIGHTNING ARRESTERS*

BY E. E. F. CREIGHTON

The installation of lightning arresters is of the nature of an insurance. A certain percentage of the cost of the apparatus can reasonably be invested as a safeguard in protecting the apparatus. Furthermore, a percentage of the income can also be invested in protective apparatus as an insurance against interruption of service. The value of uninterrupted service depends upon the nature of the use of the current and will consequently vary in different plants. Plants which make contracts involving penalties for interrupted service naturally put a higher premium on good service. Protecting the insulation of the apparatus has been an easier matter than protecting the continuity of service. It has sometimes happened that the service has been interrupted by the action of the protective apparatus itself. This is especially true in the case of a grounded phase on an insulated delta or Y system.

It is the opinion of the writer that we have in view complete protection at the terminals of the lightning arrester apparatus against any high potential surge above 150% of the normal voltage of the system, regardless of the natural frequency of the surges and the duration of their application and also regardless of the cause of the surges. Direct strokes of lightning on a transmission line must of course be taken care of where they strike. Arresters at some distance away in the station can be expected to take care of only that part of the charge which reaches the station. How thoroughly a grounded overhead wire will pro-

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* This is the first of two papers on this subject.

protect the line from direct strokes has not been fully determined, or otherwise put, how many and what conditions of overhead grounded wires are necessary to protect the line against direct strokes of lightning is not definitely known.

Arresters can be built to take care of high-frequency surges, low-frequency surges, grounded-phase surges during an hour or so, and standing waves. This leaves the causes of interruption of the electrical circuit limited to short-circuits. These short-circuits may be limited to accidental conditions, such as a wire thrown across the transmission line, overheated apparatus, etc.

On the Design of Multigap Arrester.

The novel features of a new multigap arrester consist first, of the discovery of a true nonarcing condition of shunted gaps; secondly, a combination in a cumulative manner of several shunt resistances, and thirdly, the design of ohmic resistance by the volume method rather than by the radiating surface.

First; *Absolute Nonarcing Condition.* The term "non-arcing" has long been misused in the sense of arcing during only the brief time of a half cycle or only a few cycles of the generator wave. This action is more correctly described by the term rectifying. By the term "non-arcing" in the present application it is meant that the condition of sparking exists without the formation of an arc. Transition of a spark, where the conducting medium is the heated air, to an arc where the passage of electricity is accomplished by means of convection in the arc stream of zinc vapor, involves the expenditure not only of energy but also of power.

The discharge of several hundred amperes for a brief period has been produced across a gap without bringing the difference of potential across the gap down to the normal value of 40 volts, corresponding to a current of one ampere. The power in this case was large as compared to the energy. In this connection brief periods approximating 1/100,000 second are considered. It seems to require an expenditure of power for a much longer time to bring the arc voltage down to even 100 volts. As the heating continues the voltage decreases. This effect is shown in Fig. 1. The voltage of any increasing value of current is higher than the voltage of the corresponding decreasing value, (see the two lower curves).

The difficulty in the initial transition from the condition of spark to the condition of arc is shown by another test on the same brass cylinders. Forty-five volts from a storage battery were applied to a 1/32-in. gap and a discharge of a Tesla coil was passed continuously across the gap for several minutes without causing an arc to form. In other words the battery gave out no energy. This is a case of a considerable energy at low power failing to cause an arc. It is seen from Fig. 1, however, if the impressed voltage of the battery is higher the arc will form and the arc voltage will drop far below 45 volts.

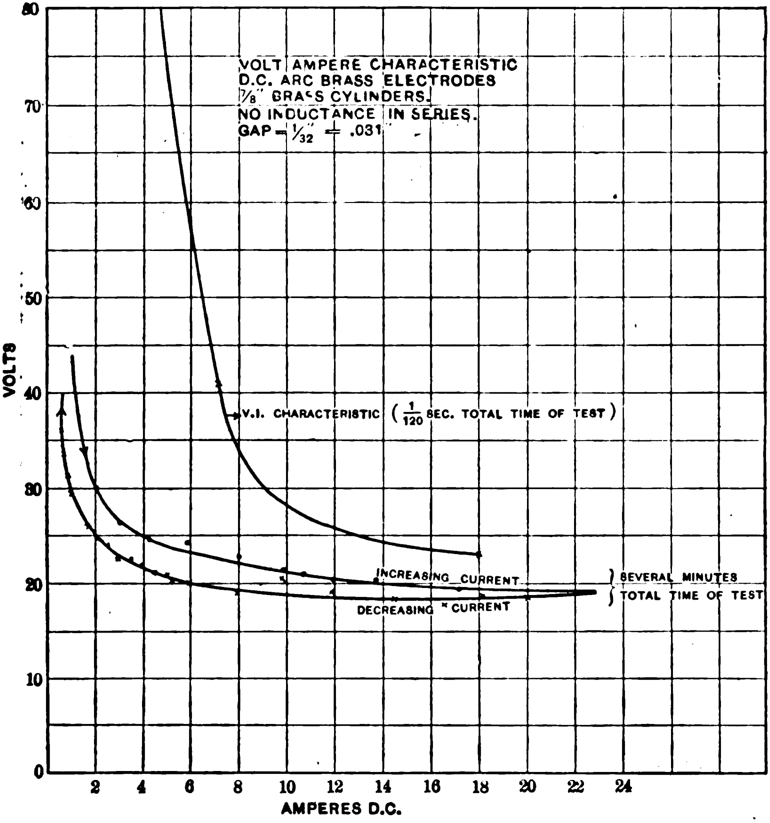


FIG. 1.

It is possible to discharge induced static electricity over multigaps directly to ground without the intervention of series resistance and still prevent the dynamic current of the generator from following the static spark, with the resultant short circuit. This condition requires an adjustment of the resistance in parallel with the gaps such that the current will be transferred to the resistance before the heat expended in the gaps is sufficient to bring the arc voltage to a low value. The problem is that of the instability of an arc (which is well known) under the unknown condition of volt-ampere characteristic of an initially established arc. The condition of instability of an arc and resistance in parallel will now be considered using the volt-ampere characteristic (middle curve) of Fig. 1. This curve shows that the arc is extinguished by any resistance in parallel which reduces the current of the arc to about four amperes. Below four ampere the rate of decrease of current is less than the rate of increase of voltage, therefore the current will increase continuously in the shunt resistance, stealing away all the current from the arc.

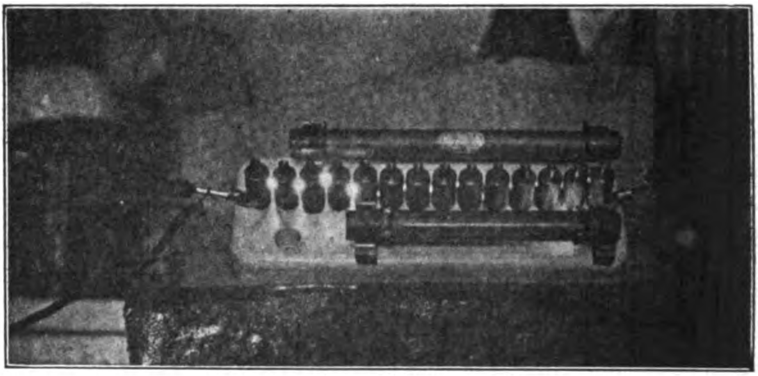


Fig. 2.—Combined non-arcing and rectifying arrester. The resistance on the near side of the gaps is of low value. It has cap contacts in the slips. The nine gaps in shunt with this low resistance are bridged by a static spark having an initial current value estimated at 1000 amperes. The spark has a clean cut outline and illuminates the cylinders near it. In the four remaining gaps to the left the dynamic current is established by the same static discharge. The blurred impression of the arc is due to the sudden expansion of the zinc vapor. The resistance back of the cylinders has a high value and plays no appreciable part in the dynamic discharge. The nine gaps show the new principle of the absolutely non-arcing condition.

The assumption is made that the total current is constant. This assumption is usually permissible. The value of resistance in parallel which causes the arc to become unstable depends on the value of total current; the higher the total current the less must be this value of resistance. For example, in the volt-ampere curve considered, if the total current is 10 amperes, it requires four ohms in parallel to make the arc go out. If the total current is 22 amperes, the shunt resistance must be reduced to 1.3 ohms to extinguish the arc. If the total current is 500 amperes the resistance is parallel must be reduced to 0.05 ohms.

This last mentioned value is too low to be of practical importance. Lightning discharges may easily reach 500 amperes, but it must be recalled that the volt-ampere-characteristic curve of the initial discharge lies far above the two curves given in Fig. 1, consequently a very useful value of a few ohms per gap will extinguish this spark before the dynamic arc can be established. The more favorable condition for the shunting of the gaps when the arc is just being started is shown in the upper curve of Fig. 1. The values of this curve were taken from an oscillogram of the voltage across one gap of an arrester during the brief period of a half cycle (1/120 sec).

Fig. 2 is a photograph of the combined discharge of static electricity and dynamic current. In the shunt gaps there is nothing but the spark, whereas in the series gaps both the spark and arc bridge the gaps. The arc is shown in the photograph by its greater size and explosive stream of zinc vapor.

Fig. 3 is an oscillogram of the currents of the two shunt circuits and the potential across the arrester when the factor of safety is diminshed by having only six gaps in the parallel path. The potential across the arrester drops from 3,200 volts maximum to 2670 volts maximum due to the line drop and the regulation of the generator.

In order to avoid confusing the above described phenomenon with the usual familiar conditions of shunted multigap, a distinction is herewith pointed out. The unstable condition of a shunted arc has been known for a long time; but this instability has to do principally with alternating current, whereas in this case only half a cycle of the generator potential is considered; in other words, we are treating the instability of a shunted direct current arc during the initially brief period of formation.

Fig. 4 shows the phenomenon of extinction of arc in the shunt gaps by shunt resistance at the end of the first half-cycle. The arc in the series gaps was extinguished at the end of the second half-cycle. This is the effect previously obtained in shunt resistances where heavy currents were used. In this test the ohms per shunted gap were too great to suppress the initial arc.

There is still much research to be done to determine the exact nature of the phenomenon at the instant of establishing and extinguishing an arc. Most of the results are of academic interest only. Here are some queries. In the extinction of the arc in the series gap at the end of the half cycle in which the discharge takes place, how much effect is due to rectification of the zinc vapor and how much to the cooling of the arc during the brief period of zero current? The answer is not simple, we know. For small currents, the effect is almost entirely due to cooling; for large currents, rectification by the zinc vapor is more prominent. The distinction is liable to be obscured by the two auxiliary accompanying conditions—first, the ionization of the air around the zinc arc and, second, by the splashing across the gap of the superfluous molten metal in the crater of the arc. Some years ago Mr. Thomas stated that it was necessary to limit the current in a multigap arrester in order to get

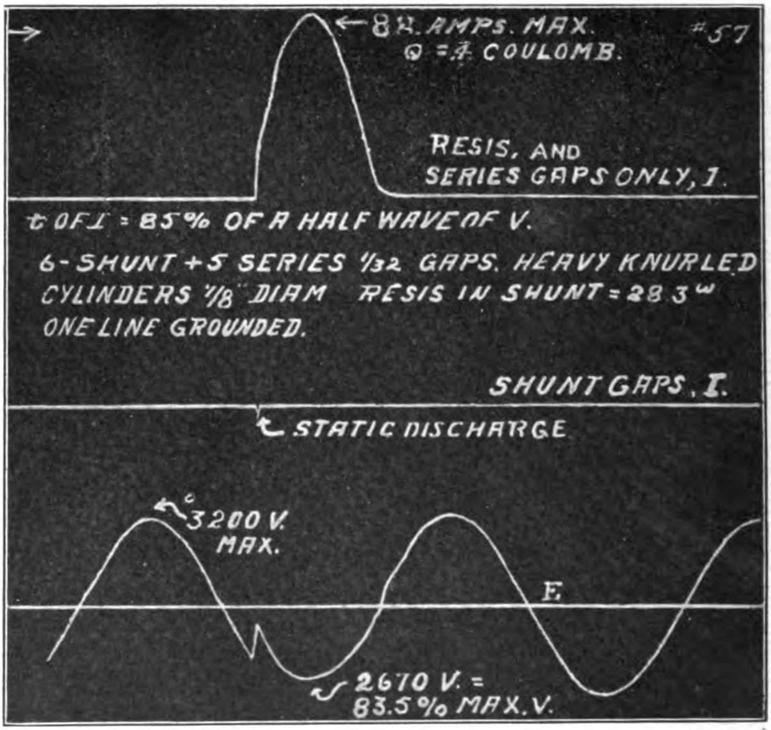


FIG. 3.—Oscillogram 57. Dynamic discharge when gaps are shunted to the absolute non-arcing condition. The upper curve is the current wave through the series gaps and low resistance. The middle curve shows the static discharge (and what little dynamic follows) in the shunted gaps. The lower curve shows the potential across the arrester inside the lightning arrester choke coils. The sudden drop in the voltage wave when the spark takes place is due to the regulation of the circuit. There is a 16% drop. The actual maximum voltage across the arrester is 2670 max. This is divided thus: 2590 volts across the resistance and 80 volts across the series gaps.

successful operation and also that the extinction of the arc was accomplished with greater difficulty if the circuit was inductive. The explanation of these facts have a practical bearing on the matter given further on in this paper.

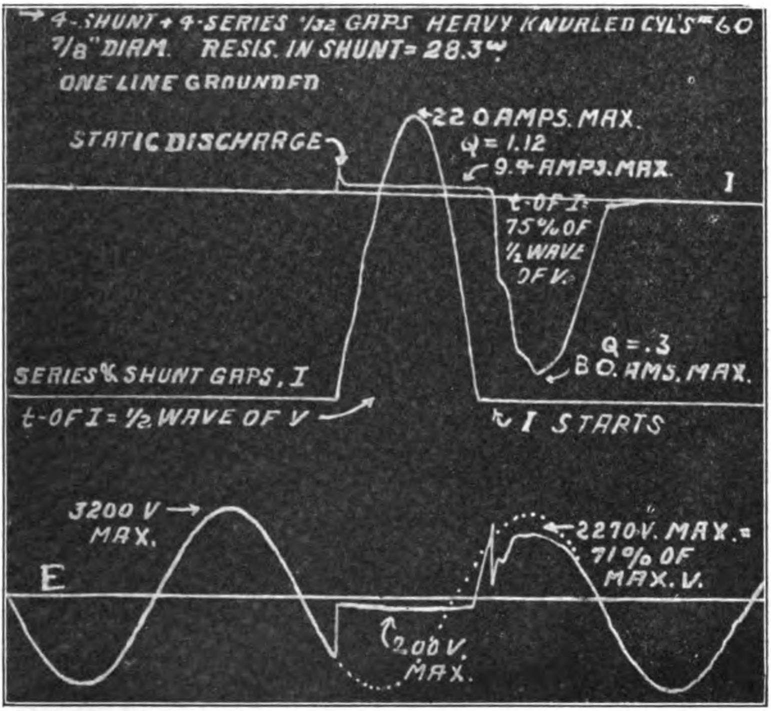


Fig. 4.—Oscillogram 60. Failure of shunt resistance. Former "non-arcing" condition. There are only 4 gaps in shunt with 28 ohms. The upper curve is the current through the resistance. Note the point marked "static discharge," the current in the resistance starts at a value greater than can be maintained. The current in the resistance is equal to the voltage across the shunt gaps divided by the resistance. This peak value bears out the statement that both energy and time are necessary to form a stable arc of normally low voltage value. The middle curve shows nearly short-circuit condition of the circuit. Note that this current lags the potential while the current in the wave above with resistance in series is in phase. The lower curve, the potential wave shows the condiion of sensibly short-circuit in the first half-cycle and the recovery in the second half-cycle. Note in the second half-cycle that the voltage jumps to about 2500 volts before the current is reversed in the series gaps.

Current Effect.—The extinction of an established arc in a multigap arrester cannot take place until the potential reduces to zero at the end of the half cycle in which the discharge takes place. Incidentally it may be remarked that if the arrester functions properly the arc should not extend over the second half cycle. (Assuming no high potential surge reestablishes the arc). If the rectifying power is not sufficient to extinguish the arc at the end of the first half cycle, it surely will be unable to do so at any instant later on account of the heated metal in the arc crater. (See Fig. 9). Consequently such an arc can be extinguished only by the flashing out of the multiarcs in one long arc in front of the arrester unit, the opening of the circuit elsewhere by a fuse or switch, or by the decrease in the generator electromotive force. This decrease in potential will be due to the reaction of the armature current on the field winding. Assume then that the arrester functions properly, and furthermore that the spark takes place on the rising point of the electromotive force wave, this gives the greatest possible discharge of dynamic electricity. The energy loss in each arc will be equal to 16 volts multiplied by the current. In other words, as the current increases there is a concentration of energy at the arc crater which melts more zinc than is necessary to supply the arc vapor. This molten zinc is splashed across the gaps and destroys the rectifying qualities of its vapor.

In consequence of the necessity of limiting the dynamic urrent, some designers have chosen between two evils and introduced series resistance into the arrester circuit. Other designers choose the evil of a possible short circuit. One improvement in design for this year is the use of a shunt resistance so proportioned as to prevent the dynamic current flowing in its parallel gaps, yet allowing a high-potential, high-frequency discharge to pass freely across the shunt gaps to ground, if the resistance offers an objectionable impedance. There is resistance for the dynamic but no resistance for heavy static discharges.

Inductive Circuit Effect.—Oscillograms show that if the arrester circuit is inductive the arc is not extinguished until the potential has passed through zero and is well along in the second half-cycle. Since the arc voltage is only 16 volts per gap for heavy currents the condition is nearly equivalent to a short circuit. When the current dies out the voltage across the gaps suddenly jumps to the value generated. (See Fig. 5). The arc has no time to cool and presumably the ionized air around the arc starts the current in the opposite direction. This condition is to be compared later to the condition of arc extinction in the liquid electrode arrester, where the current reduces to zero before the potential.

2. Cumulative shunt resistance. Referring to the diagrammatic condition of Fig. 6, gaps No. 8, 9, and 10 are protected from dynamic current by the relation of the shunt resistance (*r*). The resistance (*r*) is small and requires, seven series gaps, Nos. 1, 2, 3, 4, 5, 6, and 7 to extinguish the dynamic arc. Under certain low-frequency conditions of discharge this number of series gaps is objectionably great. Consequently this number is cut down to, say, three gaps, No. 1, 2, and 3, and in order to extinguish the dynamic arc at the end of the first half-cycle the current must be less than that through the small

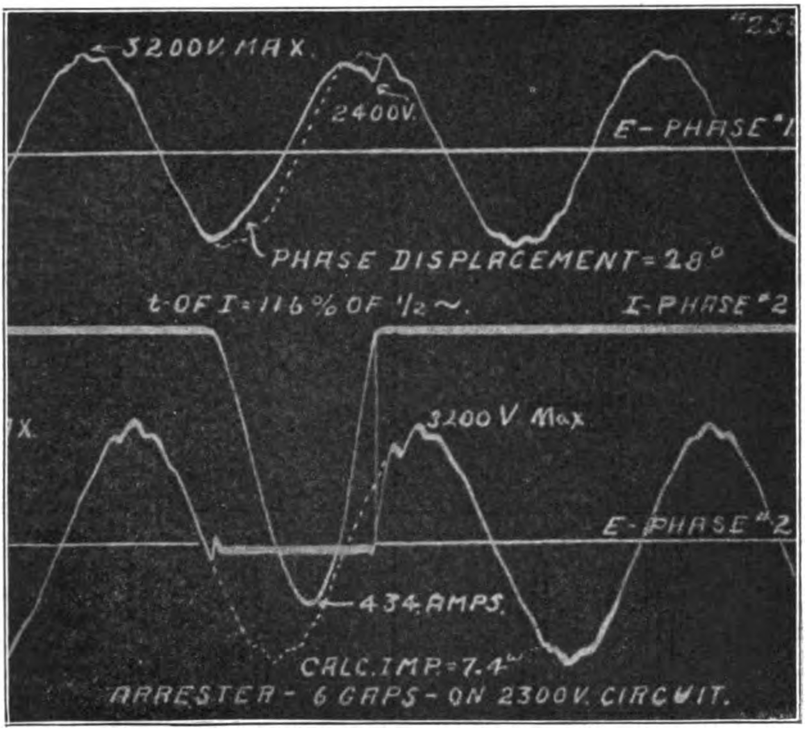


FIG. 5.—Oscillogram 253. Showing current lag, sudden recovery of potential, and displacement of another phase of the system. In the lower curve note the potential recovery when the current is extinguished. The dotted curve shows the original form of the wave. The middle curve shows 434 amperes short-circuit current. There were 3 miles of line wire to the generating station. The upper curve shows the phase displacement in phase 1 due to the reaction of the armature current in phase 2. It is noteworthy that the voltage wave of phase 1 did not have a peak value above normal maximum of 3200 volts during this interval.

resistance (*r*); the relation of the larger resistance (*R*) to the gaps numbered 4 to 10 inclusive is not such as to obtain the arcless condition of the gaps. The arcless condition of the gaps 4, 5, 6, and 7 is obtained through the presence of the small resistance (*r*) in shunt with the large resistance (*R*). So far as the large resistance R is concerned, gaps 8, 9, and 10 cannot be considered in the shunted circuit. In this cumulative manner of installing the resistance, the series gaps may be reduced to as near the spark potential of the normal circuit voltage as desired. Each time the series gaps are reduced, the resistance must be increased to such a value as to maintain the arc extinguishing effect.

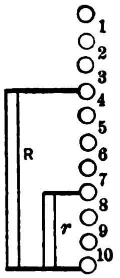
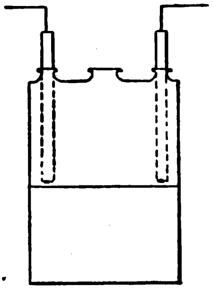
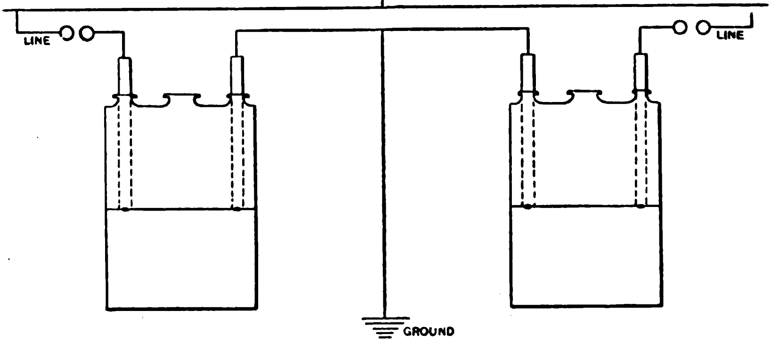


FIGURE NO. 6.



LIQUID ELECTRODE CELL
FIGURE NO. 7.



LIQUID ELECTRODE ARRESTER
FIGURE NO. 8.

FIGS. 6, 7, AND 8.

Design of Lightning Arrester Resistance. Except in the case of recurring high potential surges the multigap arrester should extinguish the dynamic arc within the time of a cycle of the generator wave. This period of time is so brief that radiation of heat need not be considered in the design of the resistance. The basis of design is the utilization of the specific heat or the heat capacity of the resistor. In the lower resistances of the lightning arrester it would be impracticably expensive to design the resistance to radiate the energy that would be lost therein if the current were applied even for several seconds.

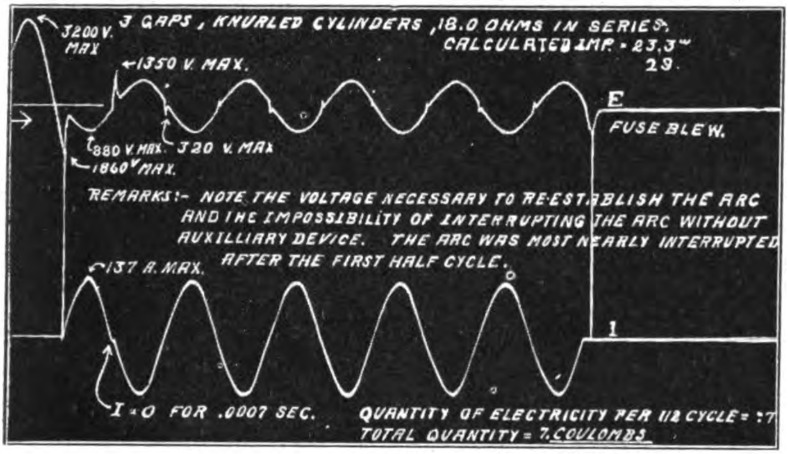


FIG. 9.—Oscillogram 29. Three gaps and 18 ohms on a 2300 V. (effective) circuit. Arrester fails to interrupt the current of 137 amp. maximum. If the arc is not extinguished at the end of the first half-cycle, the rectifying effect is lost. The spark takes place at 1860 volts increasing potential. The voltage then drops due to line resistance, etc., and reaches 880 volts max. instead of 3200. At the end of the first half-cycle the potential rises to 1350 before the current is reversed. At the end of the second half-cycle it requires only 320 volts to reverse the current. At the end of the first half-cycle on the current wave, the current remains zero for a brief period. This effect does not reoccur at the end of any subsequent half-cycle. If the current had been less three gaps would have extinguished the arc at the end of the first half-cycle.

E^2 over R multiplied by the time of a half cycle gives the energy to be absorbed. This value of energy must equal the product of the specific heat times the weight of material times the temperature times 4.2.

Assuming a safe temperature and factory of safety the weight of the material can thus be determined.

The specific resistance of the material must be chosen so as to give a length of rod great enough at least to prevent the formation of an arc along the surface. In the matter of selection of material for the resistance, notable improvements have been made.

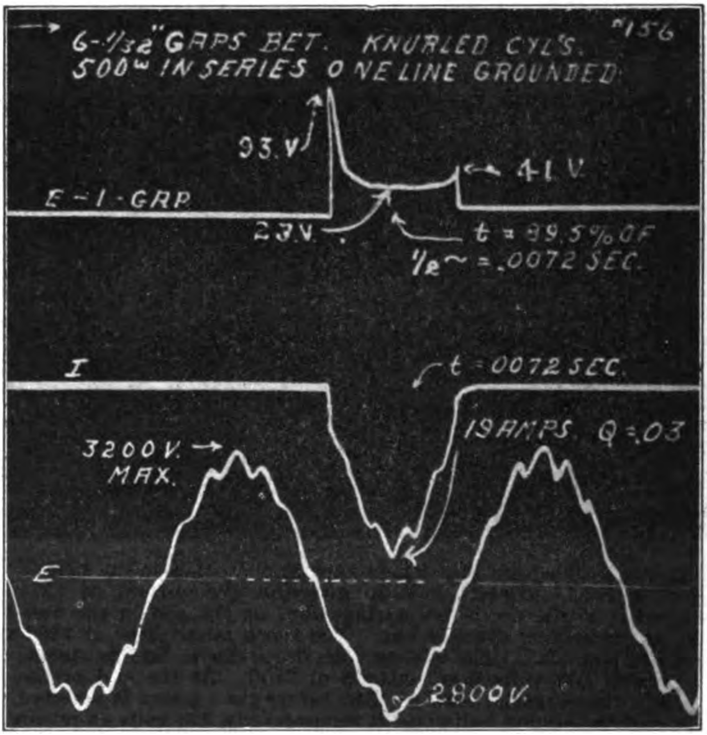


FIG. 10.—Oscillogram 156. Voltage and current of one gap of a multi-gap arrester. The oscillogram shows an initial voltage of 93 volts. The drop from spark voltage to 93 volts was too rapid to be registered by the oscillograph vibrator. This sudden drop in potential was due to the heavy discharge from Leyden jars at a frequency estimated at 3,000,000 cycles. The decrease in voltage from 93 to 23 volts is very gradual with this value of current density. The upper volt-ampere characteristic curve of Fig. 1 was taken from this oscillogram.

LIQUID ELECTRODE ARRESTER.

The name "liquid electrode" is herewith given to a new form of electrolytic type of arrester, to distinguish it from the other cell types of arresters, such, for example, as the aluminum-cell type which the writer has been working on during several years. The liquid electrode is the distinguishing feature of this electrolytic type, whereas the hydroxide film of aluminum on the aluminum plate is the characteristic feature of the aluminum-cell type. The phenomena which can be produced by the discharge of electric currents through electrolytes are of such a nature as to make valuable the employment of an electrolyte in protective apparatus. The main effect obtained in each

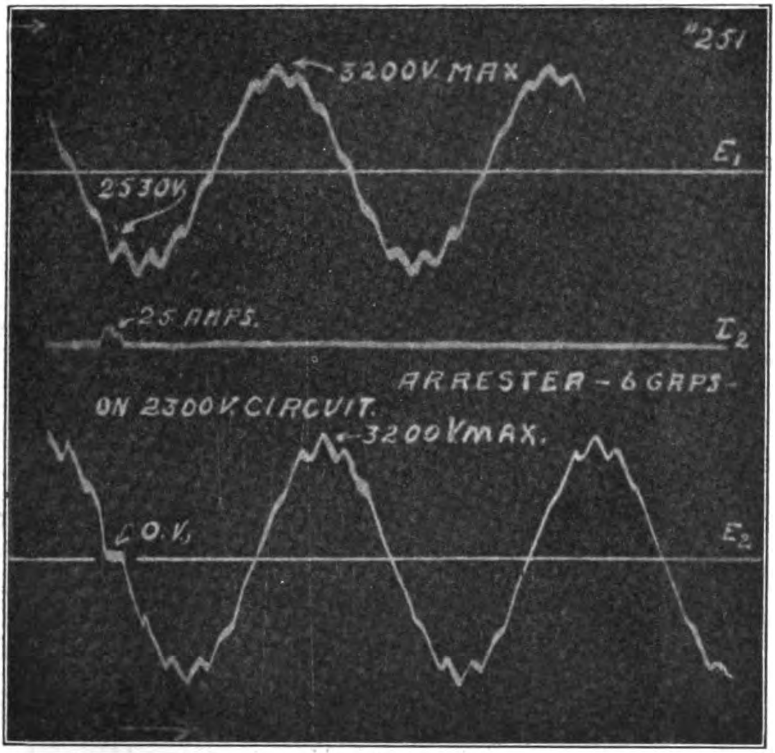


Fig. 11.—Oscillogram 251. Six gaps and no series resistance on a 3-phase circuit of 2300 volts effective. The middle and lower curves are of the same phase. These show a discharge of dynamic current where the spark takes place on the descending part of the potential wave. In spite of the short-circuit of the gaps the dynamic current rises only to 25 amperes. In practice the spark may of course take place at any point of the potential waves. In a poorly designed arrester if by chance the spark should happen when the potential is approaching zero the arrester will extinguish the arc satisfactorily; if, on the other hand, the spark takes place on the rising potential the effect may be that shown in Fig. 9. This oscillogram shows the futility of testing arresters without a synchronous switch to control time of spark discharge.

case may be designated as a *critical limiting voltage*. The employment of a *critical limiting voltage* in lightning arresters permits the design of an arrester which will limit or suppress entirely the dynamic current at normal potentials, without the use of series resistance. Abnormal potentials above the *critical limiting voltage* of the arrester discharge current through the arrester freely without obstruction of either counter electromotive force or appreciable ohmic resistance. The characteristic action of the electrolytic types can be summed up in one sentence: obstructed discharge of electricity at normal potentials of the circuit and free discharge of electricity at abnormal potentials. The electrolytic types give great promise.

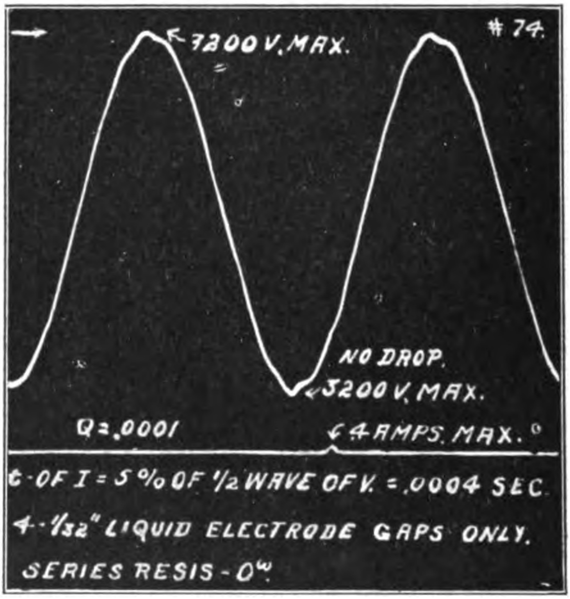


Fig. 12.—Oscillogram 74. Liquid electrode arrester using gaps at the surface of the electrolyte. Two cells in series. The current rises only to 0.4 amperes and there is no disturbance in the potential wave.

The liquid electrode arrester may have any one of several forms all involving the same principal. One form is shown in Fig. 7. Two metallic electrodes extend into a vessel containing an electrolyte of high conductivity. The electrodes may be dipped into the electrolyte or there may be a small gap left between the electrode and the electrolyte If current is passed from one electrode to the other in either direction, the liquid must become negative at one or the other electrode. It requires about 1500 volts to maintain the current through the cell in spite of the fact that the resistance of the cell is extremely low. The current is limited by the so-called counter electromotive force of the arc.

Electrodes not in Contact. The difference in effect produced by the conditions of contact between the electrodes as compared to the air-gap setting is marked. For example, three of these cells were placed in series across a circuit having an impressed voltage of 2300 volts effective. Each electrode was set with a small gap. The equivalent needle-gap was the same as for four $\frac{1}{32}$-in. gaps between standard brass cylinders without series resistance. With this arrangement several hundred static discharges having an initial value estimated at 1000 amperes were passed through the cell, but no

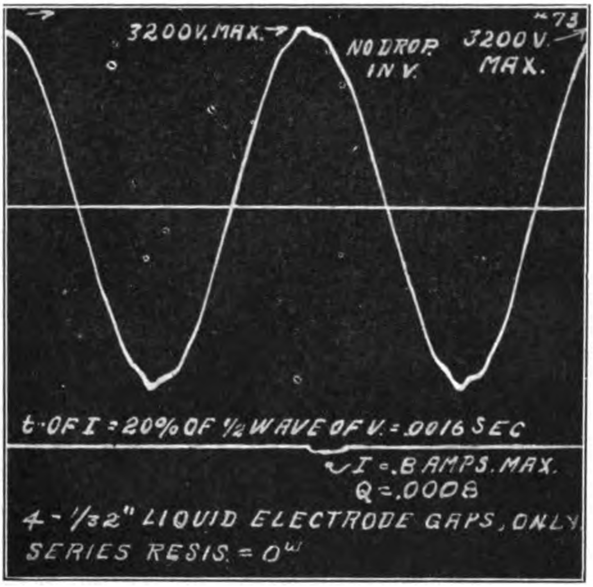


FIG. 13.—Oscillogram 73. Liquid electrode arrester using gaps at the surface of the electrolyte. Although the spark takes place at peak voltage only 0.8 ampere of dynamic current follows. Comparing the current discharge to Fig. 12, the current is twice as great and persists for a longer time. This is due to the fact that the discharge takes place at a higher point on the potential wave. The counter e.m.f. of the cells is approximately equal to the peak voltage (3200 volts) of the circuit. There is no disturbance of the potential wave.

dynamic current followed the discharges. The novel relation of counter electromotive force practically as great as the spark voltage of the cell is obtained. The sum of the counter electromotive forces per cell is greater than the impressed voltage of the circuit, consequently a spark passes without causing the formation of an arc.

Under similar conditions in the multigap arrester using four $\frac{1}{32}$-in. gaps the spark voltage of a single gap may be in the neighborhood of 2000 volts and the spark voltage of the four gaps in series may lie between 5000 and 6000 volts. The electromotive force absorbed by a single arc in practice will be scarcely greater than 16 volts per gap or 70 volts total for the four gaps. The spark voltage is about 125 times as great as the arc voltage for a single gap or about 80 times as great for the total of the four gaps.

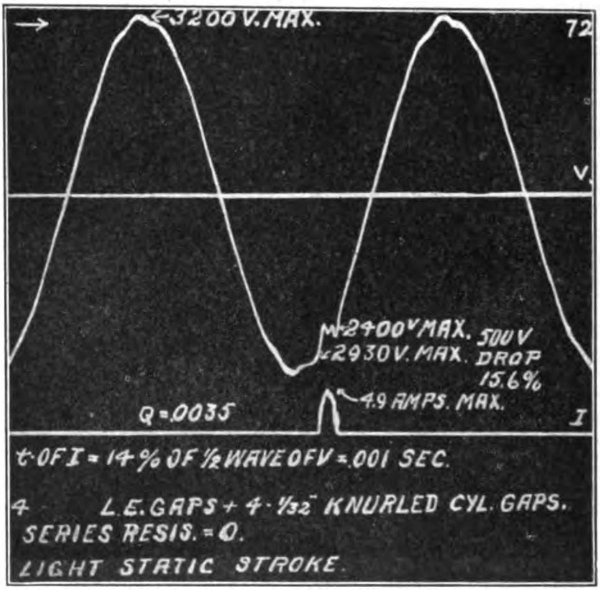


Fig. 14.—Oscillogram 72. Liquid electrode arrester using series gaps in conjunction with the small gaps above the electrolyte. There were two large lightning arrester choke coils of the pancake type in series. These choke coils give the exaggerated drop of potential (500 volts) at the instant of discharge.

Herefrom it follows that the multigap arrester does not work on the principal of counter electromotive force but upon the principal of rectification. The arrester is therefore suitable for alternating-current circuits but not at all adapted to direct-current circuits. When the currents attempt to reverse at the beginning of the second half-cycle, several hundred or even thousand volts may be required to cause the reversal. During the first half-cycle there is little obstruction to the current flowing in the arcs of the gaps, and therefore it is necessary to have an artificial resistance in series to limit the dynamic current.

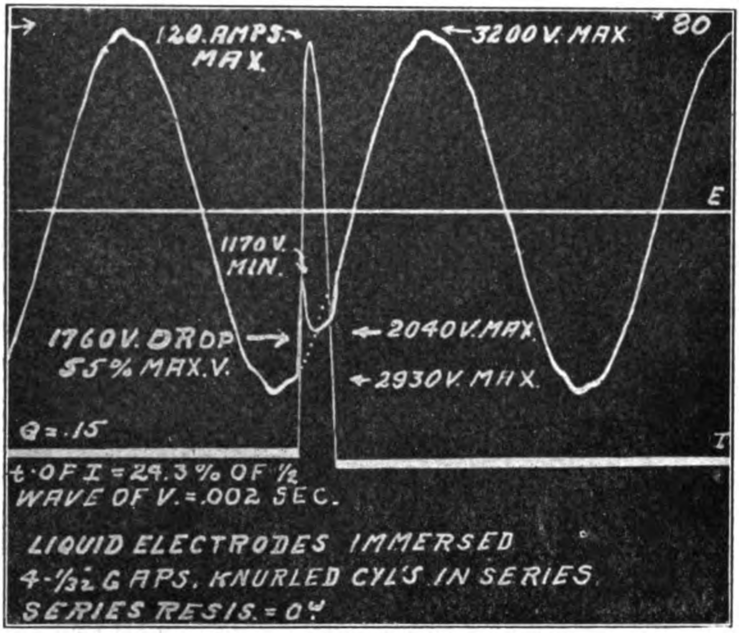


Fig. 15.—Oscillogram 80. Liquid electrode arrester with immersed terminals. The heavy lightning arrester choke coils are in series. These reactance coils add to the line drop of potential. This oscillogram shows a method of obtaining any desired quantity of dynamic discharge before the interruption of the current. The current has increased from 0.4 ampere (Fig. 12) to 120 amp. maximum due to the immersion of the metal terminals. In spite of this heavy current discharge the current decreases to zero before the potential reaches zero. Compare this to the results in Fig. 5 where the potential reaches zero and reverses before the arc is extinguished.

A liquid electrode arrester set with four gaps of equal value to the above mentioned case will have a spark voltage of 1⅓ times as great as the electromotive force absorbed by the arc, considering a single element only; or about 1.8 times as great considering both cells. On a 2300 (effective) circuit the maximum voltage is about 3200 volts. The maximum arc voltage of the two cells containing a particular electrolyte is about 3000 volts. A spark can form into an arc only at the peak value and is extinguished long before the generator voltages reaches zero. Any voltage above 1500 volts per cell produces a rush of current in proportion to the pressure above 1500 volts. In other words, the cell has a critical voltage above which there is a free discharge of electricity without the intervention of anything more than a slight ohmic resistance. In the foregoing explanation only general considerations have been held in view. Some of the experimental data from which the conclusions were drawn are given later in the form of oscillograms.

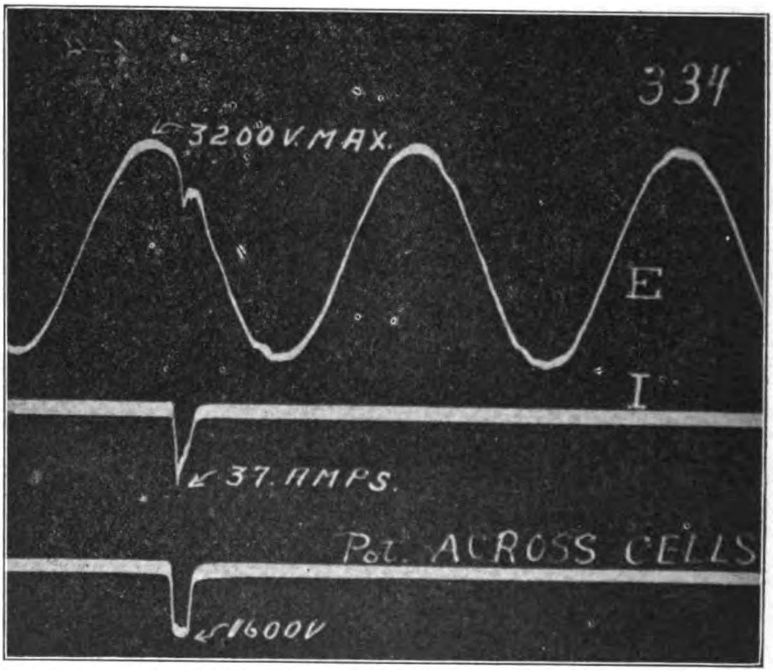


FIG. 16.—Oscillogram 334. Liquid electrode arrester with the metallic electrodes slightly in contact. The upper curve, the potential wave, is only slightly distorted. The middle curve, the current wave, rises rapidly to 37 amperes and diminishes gradually to zero. The lower curve, the potential across the cell, rises with the same abruptness as the current wave, maintains a constant value while the electromagnetic energy of the circuit is discharging and then drops quickly to zero when no longer required to oppose the current discharge.

Electrodes in Contact.—When the metallic electrodes touch the liquid it is necessary to introduce a single gap in series to hold back the line potential. Since the counter electromotive force of arcs in the arrester limit the current, this single gap suffices even at the high potentials used on long-distance transmission circuits. A simple arrester circuit is shown in Fig. 8. The series gaps may be set at any value above line potential. When the potential breaks across the gaps the current begins to discharge at short-circuit rate. The current density at the electrodes is such as to start an arc which throws the electrolyte away from the electrode and automatically

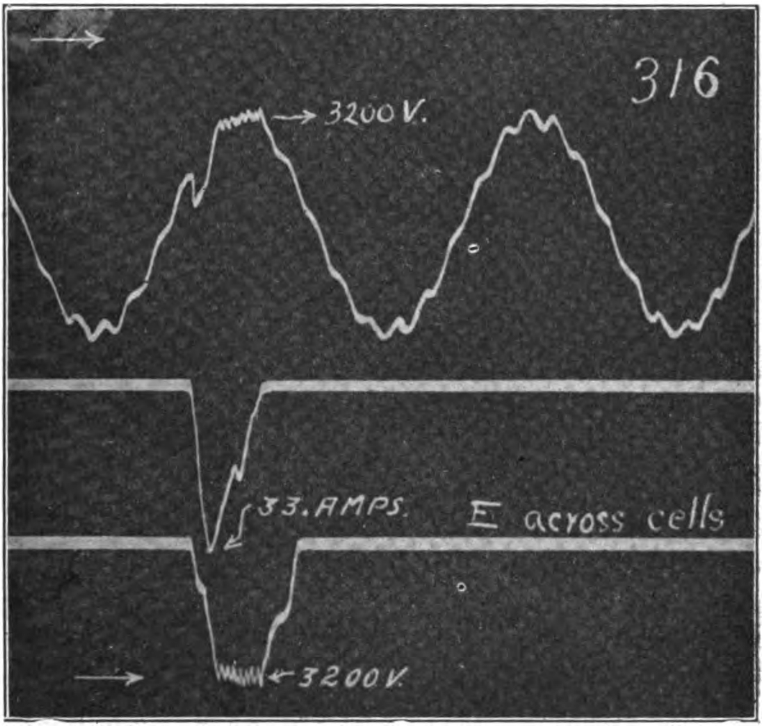


Fig. 17.—Oscillogram 316. Liquid electrode arrester with the metallic electrodes in contact with the electrolyte. The static discharge takes place on the rising part of the potential wave. The drop in the upper potential wave is due to the inductance of the circuit. The potential wave quickly recovers its normal form. The current reduces to zero in advance of the potential. The potential across the cell reduces to zero with the potential of the generator wave. The maximum counter electromotive force of the cells is equal to the impressed voltage of the circuit.

lengthens the arc. The arc voltage is greater than the impressed voltage and consequently the current dies out. The series gaps hold back the line voltage and the electrolyte assumes again its level in contact with the electrode. The current starts on short circuit but decreases so gradually that no surges have been detected either by the oscillograph or by parallel needle gaps. Extensive experimental tests have been made on a commercial circuit of 2300 volts, 13,000 volts, and 33,000 volts normal voltage. The last mentioned circuit consisted of 30 miles of three phase line and was subjected to surges due to numerous arcs drawn out between a phase and ground. These arcs to ground attained maximum lengths of five feet.

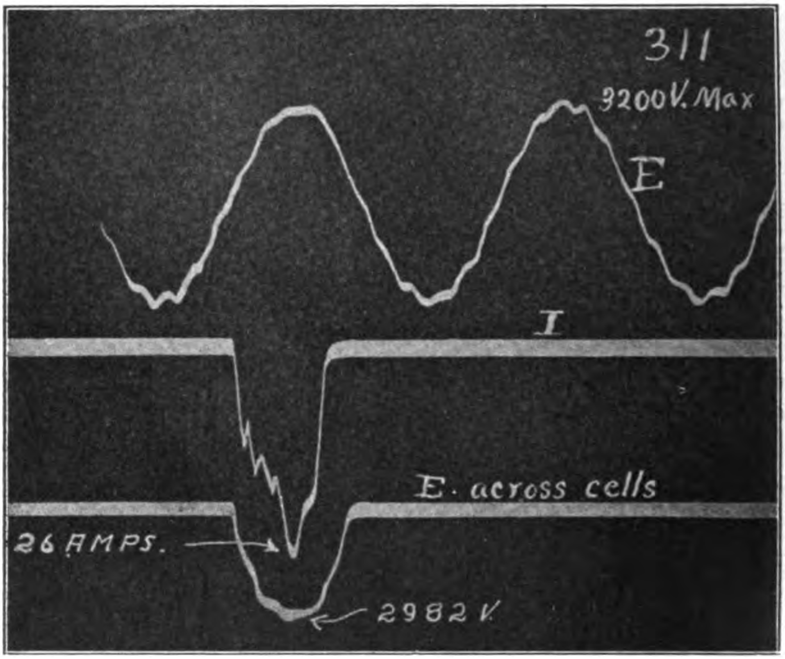


Fig. 18.—Oscillogram 311. Liquid electrode arrester with the metallic electrodes in contact with the electrolyte. The spark takes place near the zero value of rising potential, consequently the rise in current and potential across the cells is more gradual than in the previous oscillograms.

The arc voltage of the liquid electrode depends somewhat upon the length of the arc. Since it is the current which depresses the surface of the electrolyte, the length of arc depends greatly upon the value of the current. As the current decreases the electrolyte rises toward the metallic electrode. After the first instant the phenomena are of the nature of cushion effects.

The quantity of electricity which passes through the arrester before the electromotive forces absorbed by the arcs becomes active depends upon the amount of surface of metallic electrode exposed to the liquid. This value can be increased by immersing the metal to a greater depth.

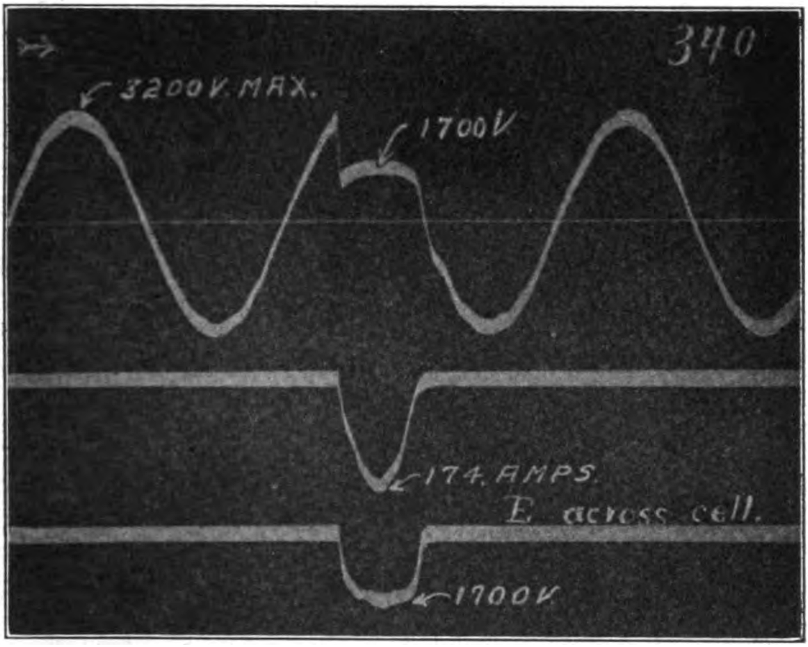


FIG. 19.—Oscillogram 340. Illustrating the critical limiting value of cell voltage. There is but one cell on a 3200 volts (max.) circuit. The spark takes place at about 3000 volts and the potential drops to 1700 volts and remains sensibly constant during the rest of the half-cycle in spite of the capacity of the generator to which it is connected. The current rises to 174 amp. maximum. This cell acts as a short-circuit for pressure above 1700 volts, but is active in opposing the current flow as soon as the pressure falls again to 1700 volts.

The ohmic resistance of the arrester is located initially in the liquid only but gradually divides between the series arc and the electrolyte. The electrolyte is a large body of large cross-section and low specific resistance, and therefore the resistance is very low.

The electromotive force absorbed by the arc at the electrolyte varies somewhat with the nature of the electrolyte.

Although the initial current may be considerable, the total current in continuous operation is not. To determine the endurance of the arrester, a 13,000-volt unit was connected to one phase of a circuit without any series gap or resistance. This circuit consisted of a 2000-kw. generator connected to nearly a mile of cable and seven miles of overhead line. The other two phases

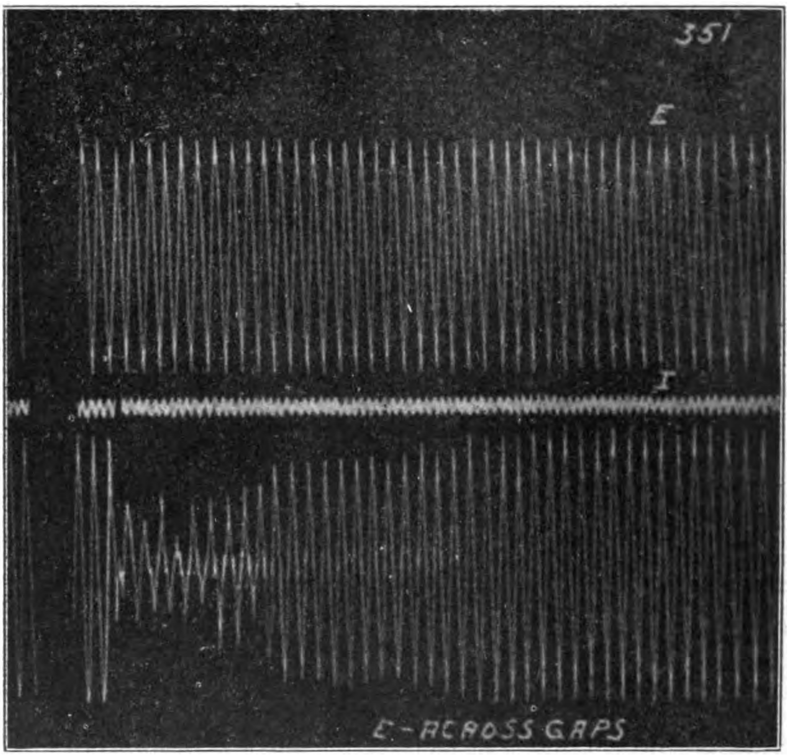


Fig. 20.—Oscillogram 351. The recovery of a liquid electrode arrester after a lightning discharge. The upper wave is the potential across the entire arrester. The lower curve is the potential across the series gaps alone. The middle wave is that of the current of discharge. The actual wave is not visible on account of poor illumination of the mirror of the vibrator, but the duration is shown by the open space in the zero line of current during the third cycle after the opening of the shutter. The potential curve across the gaps shows a drop to zero, then a gradual recovery to full line potential. During this interval the arrester is ready for a second discharge.

were protected by gaps set at 150% of line voltage. The potential of these phases did not jump the gaps during the severest tests. It should be noted that the arrester was in action under the abnormal condition of no series gaps. The action of the arcs gradually lowered the level of the liquid until 13,000 volts would no longer maintain the arcs. The time required to do this depends on the construction of the

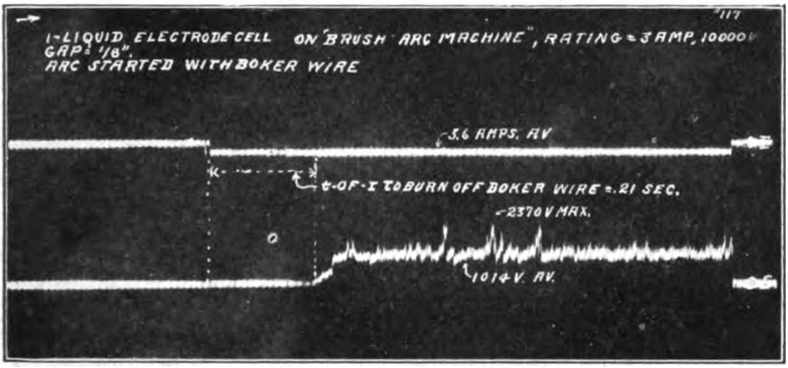


FIG. 21.—Oscillogram 117. Liquid electrode cell on 3.6 amperes constant current. The voltage varies considerably due to the splashing of the electrolyte. The small lumps in the current wave are due to the irregular intensity of the oscillograph arc. The average voltage for this electrolyte and current is approximately 1000 volts. The arc was started by means of a 5 mil Boher wire. It required 0.2 sec. to burn off this fuse with the current at 3.6 amperes.

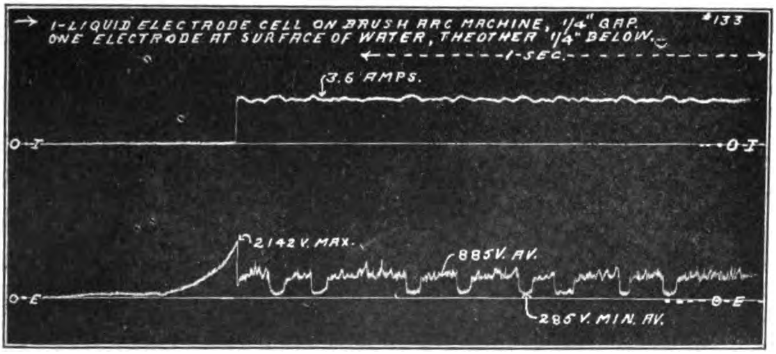


FIG. 22.—Oscillogram 133. Liquid electrode cell on direct current showing the time required for the arc to bore ¼ inch below the surface of the electrolyte. The average potential with the liquid as the negative electrode in 885 volts, but when the arc reaches the metal electrode in the liquid the voltage drops to 285 volts or less. Shortly after the liquid again sweeps over the lower metal electrode and raises the voltage again.

cells. In the small cells it is about five minutes and in the large cells somewhere between ten and twenty minutes. This time can be increased if found advisable. This sustained operation should make the liquid electrode arrester suitable to take care of the recurring surges on an isolated delta or Y system, when one phase is grounded through more or less of an arc, during a time amply sufficient to disconnect the faulty line. In the foregoing experiment a 20-ampere fuse in series with the arrester was unaffected. Apparently the possibility of an interruption in practice due to the short circuit of the arrester can be eleminated as it was in this test.

In practice the number of cells would be chosen to give a critical limiting voltage of 125% to 140% of the impressed voltage. The gap length may be set to give any desired protection. Since the arrester has but a single gap, the spark potential is as near independent of the natural frequency of the lightning surge as possible. It should discharge with facility low-frequency surges. It has a small dielectric spark lag.

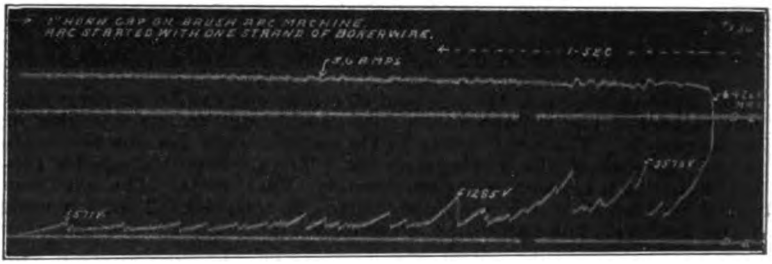


FIG. 23.—Oscillogram 136. Potential of a horn gap discharging 36 amperes constant current. The arc rose up the horns with considerable difficulty. The arc would flame to a peak and the potential would strike across below the peak and thus shorten the total length of the arc. The shortening of the arc would drop the potential. This effect is shown in the lower curve of the oscillogram by the repeated drops in the potential. The arc held in the narrow gap for about a second. This is shown by the low voltage of the curve. The total time the arc held was two seconds.

The characteristics of the liquid arrester have been studied in detail with the aid of an oscillograph. A few oscillograms have been chosen which show the effect of a cell on the current and potential of a commercial 2300-volt circuit. Among other things shown in these oscillograms are:

The effect of discharge at different points of the potential wave.

The effect of more or less immersion of the metallic electrode on the current and potential.

The critical limiting voltage of an electrolyte.

The critical limiting voltage of the arc in the standard multigap arrester (this is given for comparison).

The initial short-circuit effect and subsequent cushion effect.

The recovery of the cell after the discharge.

The reduction of current to zero before the potential wave reaches zero.

The writer pays his grateful homage to the originator of the oscillograph M. André Blondel. The value of the oscillograph in this work will be evident from an inspection of the oscillograms. The auxiliary apparatus necessary to get initial effects of discharges is quite essential. The problem is to place on a revolving photographic film with a total time of exposure of about 1/10 second, a static spark which will start the dynamic current flowing at any chosen point of the potential wave not varying in location by more than about 1/1000 second. In the following described combination of switches the operations are entirely automatic. It requires only the release of a latch. The oscillograph is so constructed

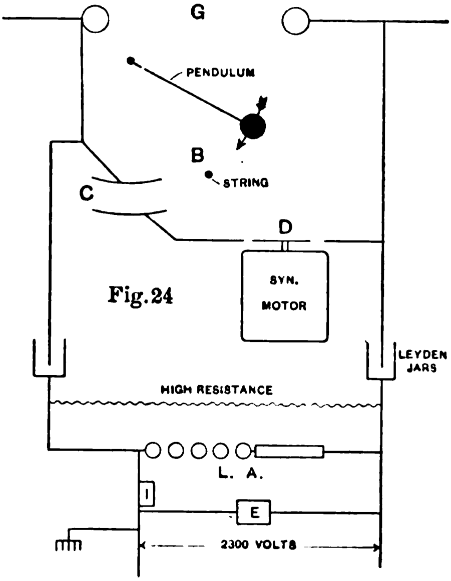


Fig. 24

that a lever operates the shutter. The shutter is opened by the lever and closed by a complete revolution of the drum carrying the photographic film. Fig. 24 shows the connections and locations of the apparatus. When the pendulum is released it strikes a string at *B* which opens the kodak shutter; it then closes the circuit between the two parallel strips during an interval depending on the velocity of the pendulum and the length of the strips. Meanwhile the synchronous motor carrying the synchronous switch at *D* closes the circuit of the static machine located at *G*. This release of the potential on the inner coatings of the Leyden jars throws the potential on to the lightning arrester *L A*, thus producing a spark across the gaps. An arc follows from the dynamic potential which is also impressed on the terminals of the lightning arrester. The vibrators of the oscillograph are shown at *E*, and *I*. The static machine is kept running at such speed that it will not spark across the gap at *C*. The potential of the static machine is also easily controlled by the application of more or less needles. These needles can be regulated to discharge the current of the static machine as rapidly as it is generated. The potential can thereby be limited to any desired value.

A paper presented at a Special Meeting of the American Institute of Electrical Engineers, New York, April 15, 1907.

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THE ROWLAND TELEGRAPHIC SYSTEM

BY LOUIS M. POTTS

Since the invention of the Morse system more than fifty years ago, telegraphy has grown by law of natural evolution to meet the demands of an increasing business. The Morse system has been the measure of the potential of the telegraph wires and of the operator. To handle a continuously increasing business, telegraph managements have been compelled to stretch annually new copper wires and to employ new operators, because the present wire systems have been worked continuously to their capacity and operators to their highest efficiency under the conditions imposed by Morse methods. It is evident that this indefinite extension of wire systems and the force of operators involves the consequent investment of enormous capital and increases indefinitely annual maintenance charges.

In all other fields of modern industrialism when manual methods have thus shown themselves to have reached the limit of their development, and to be capable only of clumsy augmentation without radical resulting advantages, necessity has found the apparatus to meet the demand, and the introduction of machines and machine methods has inaugurated a new era of increased capacity and economy. For some years, telegraph managers have realized that the manual Morse system has about reached its limit of development and they recognize that further progress must result from the use of machine telegraph methods. They have understood that the machine to be valuable must despatch a greater volume of traffic on existing wires and give greater efficiency to the operator than can be done with the now highly developed Morse methods. The field of machine telegraphy thus determined has proved to be a most fascinating one to inventors and has enlisted the constant attention and efforts of a large number of able and ingenious men. As a consequence, various telegraphic devices and machines have been brought forward at different times to meet the demand of the situation, but since none has heretofore remained predominant in the field, it is clear that none has been able to meet the exacting requirements attending commercial operation.

The purpose of this paper is to describe a system of telegraphy which meets the requirements of the telegraphic service of to-day by providing for an enlarged wire capacity, combined with greater efficiency of the operator and adaptability to the requirements than any system previously described. In practical operation, it has continuously demonstrated its efficiency in despatching an enormous volume of business with regularity and accuracy on a single wire, while the operators employed have been not necessarily skilled in the use of the Morse code.

GENERAL DESCRIPTION

The Rowland Telegraphic System is a sytem in which the two features of multiplexing and printing are combined. The multiplex feature is accomplished by the synchronous operation of the instruments at the terminal stations. By this means, in an octoplex installation each of the four operators is given the use of a telegraph wire one-fourteenth of a second, at intervals recurring 3.5 times a second.* In addition, the wire is duplexed by the polar duplex method, so that four transmissions in each direction, or eight in all, are obtained. In a quadruplex installation, each of the two operators is given the use of the wire for one-seventh of a second at intervals recurring 3.5 times a second; and the duplexing of the wire provides for two transmissions in each direction, or four in all.

The printing is accomplished by a perfectly direct method; that is, no punched or otherwise prepared tape is used at either the sending or receiving station, but the printing is controlled directly from a keyboard, practically identical with that of a typewriter. The total duration of the operation, from the depression of the key at the sending station until the character is printed at the receiving station, is less than one-quarter of a second.

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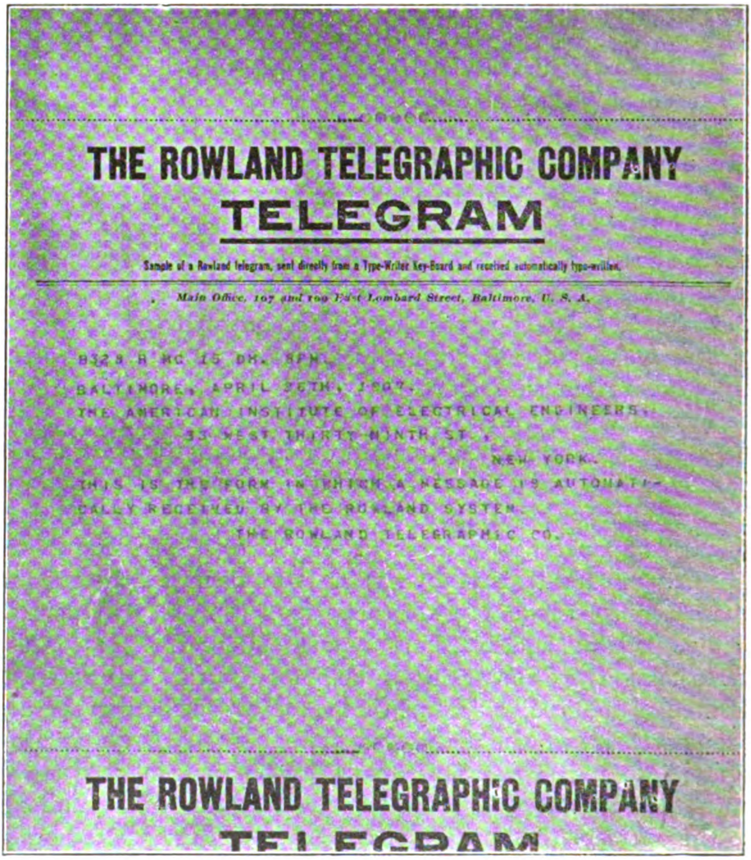
*The normal operating speed is fixed at 210 revolutions of the line unit per minute, or three and one-half revolutions per second, or one revolution in one divided by three and one-half, or two-sevenths of a second. This interval of two-sevenths of a second being divided among four operators, gives each one the use of the wire for two sevenths divided by four, or one-fourteenth of a second.

All the operations at the receiving station are controlled from the keyboard at the sending station. This keyboard is identical with a typewriter keyboard, except for three additional keys, the so-called " lining," "backing," and "blanking" keys. The lining key is for the purpose of enabling the sending operator to move the paper from line to line on the printer at the distant station, the paper being moved the distance between two consecutive lines each time this key is depressed. The backing key is used for the purpose of returning the carriage at the distant station to the beginning of a new line. The blanking key is used for the purpose of shifting a telegraph blank on the printer at the distant station to the proper position for a new message. By the use of these keys in conjunction with the other keys, the operator has perfect control over the receiving printer at the distant station. All the operations performed on a typewriter, such as paragraphing, tabulating, etc., can be performed equally well with this keyboard.

At the sending station, in addition to the keyboard there is a home-recorder and a signal light for the guidance of the operator. The home-recorder consists of a tape-printing arrangement. A narrow paper band passes directly over the keyboard, and (directly) in front of the operator. On this tape is recorded the character corresponding to each key depressed. When the lining, backing, and blanking keys are depressed, in place of performing these operations on the home-recorder, characters are printed on the tape, indicating that these keys have been operated properly. When the backing key is depressed, an arrow is printed on the tape. This arrow, as the tape moves, travels with the tape along a properly graduated scale and indicates to the operator the position of the character last printed on the page printer at the receiving station.

In addition to the home-recorder, there is placed beside the keyboard a small red signal-lamp for the guidance of the sending operator. When the carriage at the receiving station has approached within a certain number of characters of the end of the line, this signal lamp automatically lights, thus performing the same function as the bell on the type-writer and preventing the sending operator from piling letters at the end of the line. When the operator depresses the backing key, this light goes out as soon as the carriage at the distant station has returned to the beginning of a new line.

At the receiving station the messages are automatically printed in page form on a long band about eight inches wide, (See Fig. 1 for facsimile of message) which may be prepared with the regular telegraph blank, or any other blank which may be desired. On these blanks the messages may be printed in any desired form, there being the same flexibility as can be obtained by the use of a typewriter. The page printer consists of a light carriage which carries the paper and is capable of being moved in a horizontal direction for purposes of spacing.



THE ROWLAND TELEGRAPHIC COMPANY
TELEGRAM

Sample of a Rowland telegram, sent directly from a Type-Writer Key-Board and received automatically type-written.

Main Office, 107 and 109 East Lombard Street, Baltimore, U. S. A.

B328 R MC 15 DH. 5PM.
BALTIMORE, APRIL 26TH, 1907.
THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,
33 WEST THIRTY NINTH ST.,
NEW YORK.
THIS IS THE FORM IN WHICH A MESSAGE IS AUTOMATI-
CALLY RECEIVED BY THE ROWLAND SYSTEM.
THE ROWLAND TELEGRAPHIC CO.

THE ROWLAND TELEGRAPHIC COMPANY

FIG. 1—Facsimile of Rowland Telegram

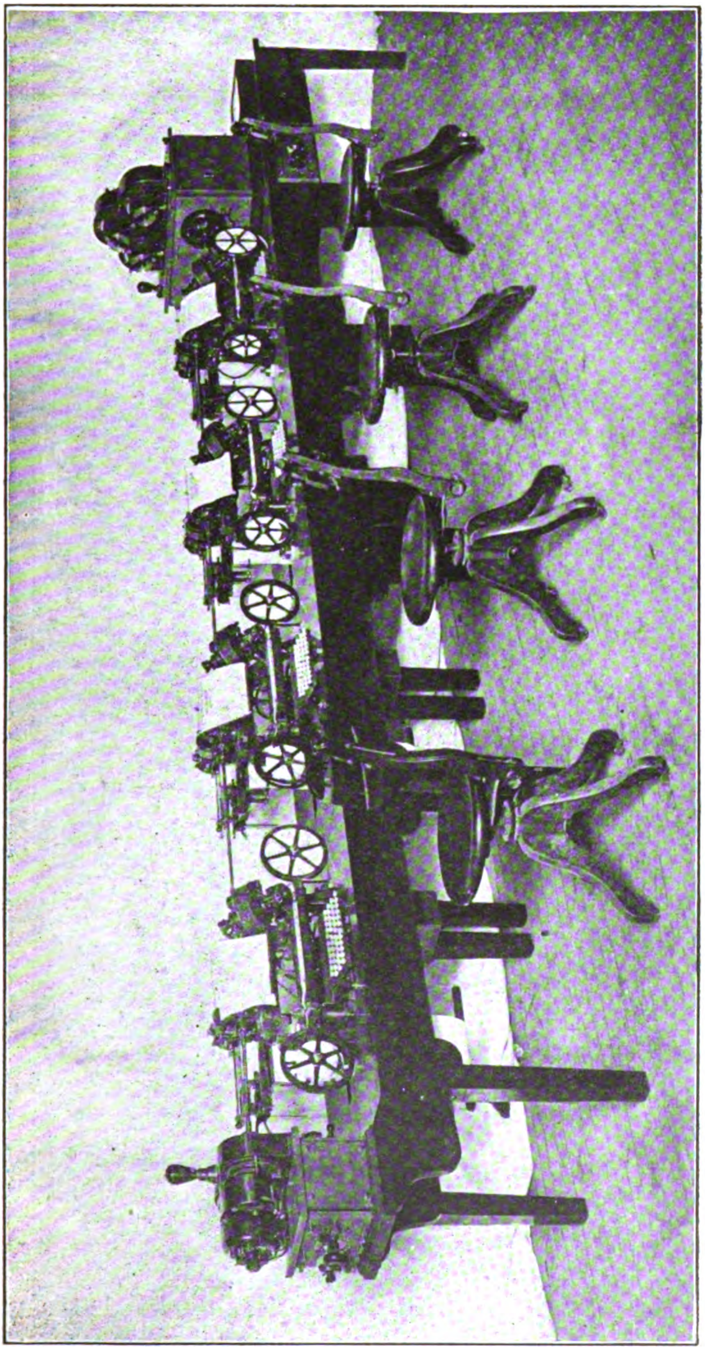


Fig. 2—Rowland Octoplex, sending side

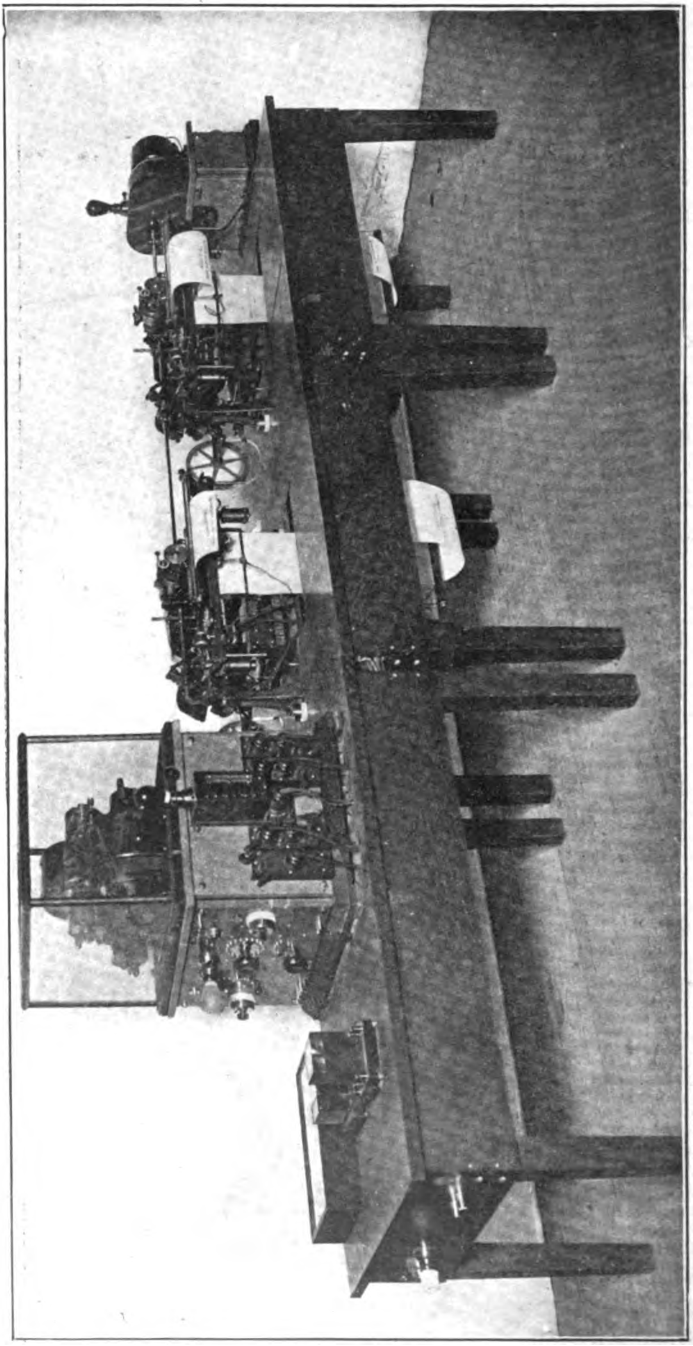


Fig. 3—Rowland Quadruplex, receiving side

The paper is carried around a roll, which by rotating places the paper in position for a new line. The paper is carried between a platen and a constantly rotating steel wheel, having the various characters engraved on its rim. When a character to be printed is directly over the platen, the platen throws the paper against the type-wheel, which is continually inked by a small felt ink-wheel. All the above motions and the operation of the platen are produced by electromagnets under the perfect control of the sending operator.

SPEED OF OPERATION

The speed of each operator is limited by the number of times per minute the keys are unlocked. The normal operating speed being 210 revolutions of the driving mechanism per minute, the keys are unlocked 3½ times each second, or 210 times per minute. One key can be depressed each time the keys are unlocked. The theoretical maximum speed is about 40 words per minute. On account of the time required for returning the carriage to the beginning of the line, and also because of the fact that the operator does not always take advantage of the unlocking of the keys, when operating for long periods, the speed in actual practice is about 35 words per minute. However, except on the longest lines the speed of the operation of the machine may be very materially augmented. Upon the basis of 30 words per message, which is generally accepted as a fair average, this speed is equivalent to a rate of about 75* messages per hour, per operator, or 300 in each direction per hour, per wire, or 600 per hour, per wire for the full octoplex.

TELEGRAPHIC CURRENT

In the Rowland system of telegraphy, the basis of the telegraphic current is an alternating current.

In an octoplex installation the current, at the normal speed of operation, has a period of 98 cycles per second. The same current is used for signalling and synchronizing. This alternating current is sent over the line continuously. The signals consist in reversing certain combinations of waves, as will be described later.

Fig. 4, Curve I, quadrant *C* is an oscillogram of a block of 14 of the half waves of the basic alternating current. The half waves are numbered from 1 to 56, after 56 another block begins with No. 1, and so on. This block of 56, which lasts two-sevenths of a second, is divided into four blocks each, *A*, *B*, *C*, and *D*, each of which is assigned to a different operator, making four transmissions each way if duplexed as mentioned. Each block recurs 3.5 times each second.

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*A rate of 71 messages per hour has been maintained in commercial practice for all-day operation. A rate of 50 to 60 messages per hour is maintained with ease.

For the purpose of sending the actual printing signals, only 11 impulses are used in each block. One of the remaining three in each block is used for operating the lamp signals between the stations, and one other, in the *D* block, is used for the letter finder impulse as is described later. The sending of a signal for the printing of a character at the distant end consists in the reversal of two of the 11 impulses. By variously combining two at a time of the 11 impulses, a sufficient number of signals is obtained for telegraphic purposes, that is, 55 possible different signals, 51 of which are actually used, any one of which may be transmitted during a time in which 11 impulses pass over the line.

Fig. 5 shows how the 11 half-waves are combined to obtain the 51 signals used.

Fig. 4, Curve 1, is an oscillogram of the current received and which vibrates the main-line relay. At the particular time of the oscillogram the *A* operator is transmitting the signal period (•) The *B* operator is transmitting the signal for lining and the *C* operator is transmitting no signal and the *D* operator is transmitting the letter *A*. The letter-finder wave is also shown reversed, as this is always reversed. The carriage on the *D* receiving printer is at the end of a line and the lamp signal in the *A* quadrant is reversed.

In a quadruplex installation the current has a period of just one-half that of the octoplex, or 49 per second; and the waves shown in the *C* and *D* blocks in Fig. 4 are omitted, the waves being numbered from 1 to 28 and after 28 the start being again made with No. 1. Each block recurs, as in the octoplex, 3.5 times a second and thus the time for each wave is twice as great as in the octoplex and the frequency is therefore one-half.

GENERATING THE ALTERNATING CURRENT

The alternating current used for the Rowland system is generated directly by the machine itself, this being necessary because the frequency of the current must correspond exactly with the speed of the machine. The current is generated by a dynamo or by a transformer and a commutator together with

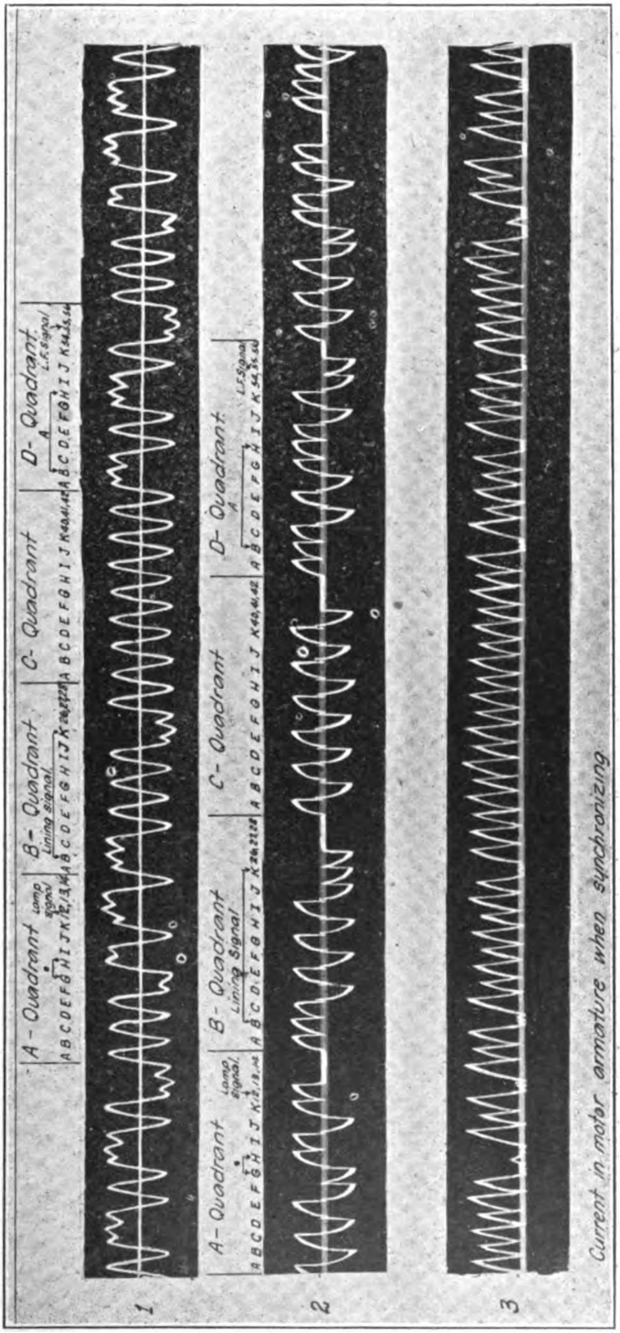

FIG. 4, Part I—Oscillogram

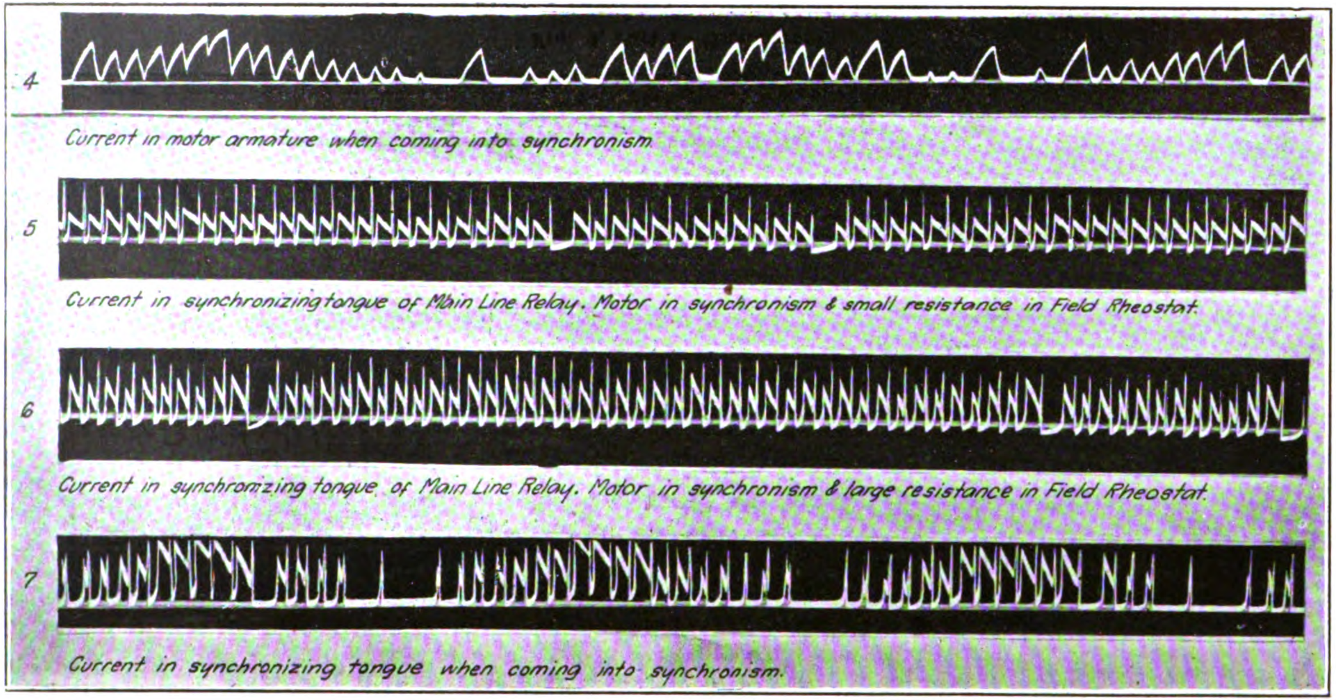

FIG. 4, Part II--Oscillogram
Curves 5, 6, and 7 above are printed in the reverse direction to that of the previous curves, and the lapse of time is from right to left, in place of left to right.

a combination of resistances and condensers which serve no other purpose than to reduce sparking on the commutator.

The transformer consists of two primary and two secondary coils with an iron core. The commutator used in connection with the current generator has eight rings, one being a solid collecting ring and the other seven being crown sections having in the octoplex 56 segments and in the quadruplex 28 segments every alternate segment being electrically connected.

One terminal of each of the two primary coils of the transformer is connected directly to negative. The other terminals are connected to the alternate segments of the first crown section, the coils being so connected that the current flows through them in such a manner as to magnetize the iron in opposite directions. The theory of the operation of this current generating apparatus should first be considered with regard only to the solid collecting ring and the first crown section (see Fig. 6), the other crown sections simply serving the purpose of stopping the spark and preventing wear of the commutator and brushes. By taking into consideration only these parts, it will be seen that the brushes (which are all in metallic connection) alternately connect the two open terminals of the two primary transformer

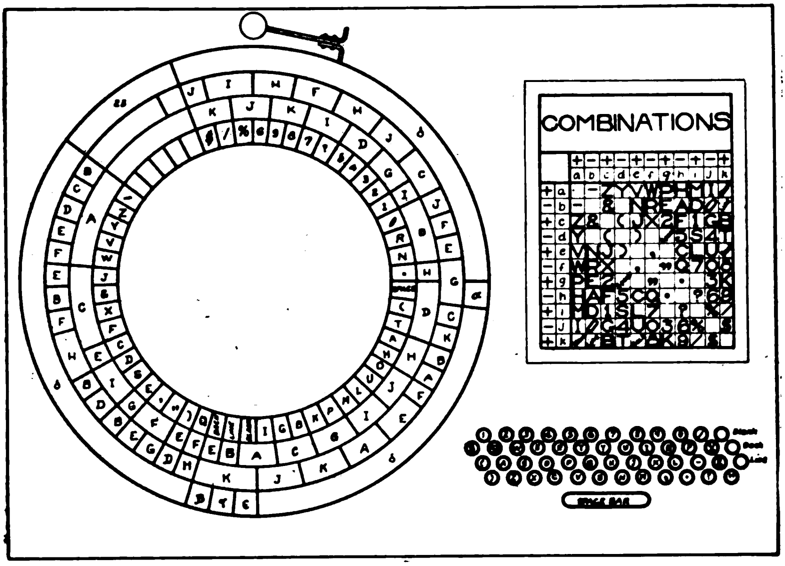

FIG. 5—Combination diagram

coils to the positive of the direct-current voltage, thus continually reversing the magnetism of the iron core of the transformer as the brushes pass from one segment to the next. These reversals of the magnetism of the iron core induce in the secondaries of the transformer an alternating current, the further operation of which will be explained later.

The remaining six crown sections of the commutator have their alternate sections connected to the two primaries in a similar manner to the first crown section, except that in place of being connected directly they are connected through resistances shunting condensers, these resistances increasing in value from the second crown section to the last. The brushes are so arranged on the trailer arm that the brushes leave corresponding segments of different rings in the order of increasing resistance. By this arrangement the spark which would otherwise occur when the brush leaves the segments is prevented.

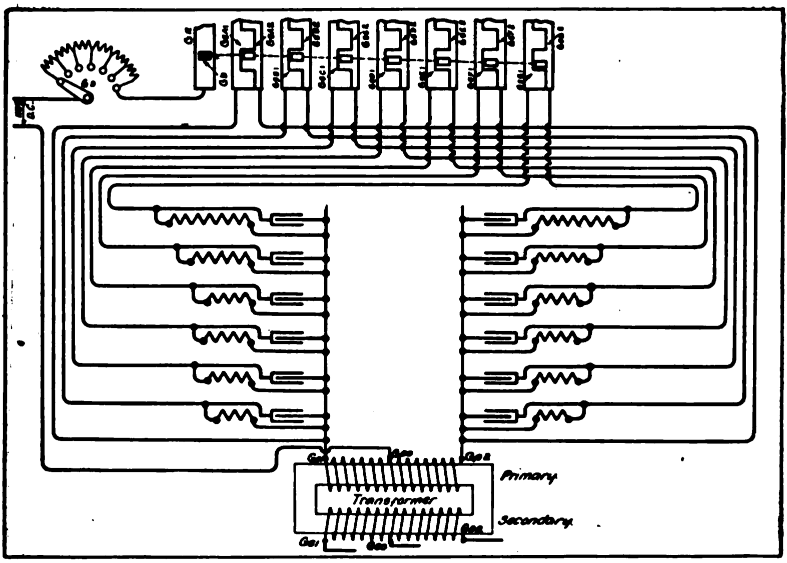

FIG. 6—Current generating connections

On the end of the brush arm opposite to that carrying the contact brushes are mounted two carriers, the first one of which carries a piece of dry felt, the second one a piece of felt slightly oiled. These two carriers are operated by springs so that the felt is pressed against the surface of the commutator in such a way that the dry piece of felt cleans the commutator while the second piece of felt furnishes the commutator with fresh lubricant. The action of these pieces of felt is to diminish the spark on the commutator and also to prevent mechanical wear on both the brushes and commutator.

AMOUNT OF CURRENT REQUIRED

In the Morse system of telegraphy, and in fact in most systems of telegraphy, it is customary to measure the currrent by applying direct voltage to the line so that the same amount of current flows at both stations. When the signalling current is reversed in direction at comparatively regular intervals there is quite a different phenomenon. In this case a greater current flows at the beginning of the line than at the end. This fact is readily understood by considering the action of the line. Each time that the current is reversed not only does a certain amount of current flow from the beginning to the end of the line, but there is also a large amount of current at the beginning of the line necessary to charge and discharge it. When the line has any considerable length, that is, a considerable capacity, the current which reaches the far end of the line will be only a small part of that which enters it. An example will illustrate: A particular line has a capacity of 8.4 mf. and a resistance of 2070 ohms, when operated in octoplex (period of current 100) 240 milliamperes were sent out at the beginning of the line and about 35 milliamperes received at the end of the line; that is, about six times as much current was required to charge and discharge the line as reached the far end of the line and actually vibrated the main-line relay. Of course, a similar state of affairs is present when a line is operated by any reverse-current system, such as the Morse duplex or quadruplex; but the phenomenon is not often observed as the steady state of the current is measured and alternating-current measuring instruments are not ordinarily required in a telegraph office.

For the proper operation of the relays used with the Rowland system, it is necessary to have at least 25 milliamperes at the receiving station. A very good practical working value for this relay is about 35 milliamperes; and when line conditions are very bad it may be found necessary to use 45 milliamperes. These values of current are required, not because the apparatus will not operate with less, but the signalling current must be sufficiently large to overbalance the effect of leakage and induction currents.

DUPLEXING

The duplex feature of the Rowland system is obtained as in many other systems of telegraphy by the use of a differentially wound relay and an artificial line, which represents as nearly as possible the real line as regards its resistance and capacity.

In order that the main-line relay may not be affected by the outgoing current, it is necessary that the currents in the two sides of the relay should be identical. In order that one may know when such is the case, a large resistance (about 5,000 ohms) is connected from one side of the relay to the other. Across a small part of this resistance (about 50 ohms) a telephone is connected.* When the currents flowing through the two sides of the relay are identical, no current will flow through this shunt and consequently there will be no sound in the telephone. By means of plugs it is possible readily to change the resistance of the artificial line, and also to move the condensers to any part of this resistance and thus to adjust the currents in the two sides of the relay until they are equal in phase and value. In the Rowland system the alternating characteristic of the current causes the balance to depend more directly on the capacity of the line than on its resistance. The balance used in its operation, therefore, is much more stable under varying conditions of the weather than in such a system as the Morse quadruplex, in which the resistance must be kept adjusted to the varying conditions, since the weather has much greater effect on the equivalent resistance of the line than on its capacity.

SYNCHRONISM

In most of the systems of multiplex telegraphy that have ever been tried the principle of synchronism has been used; that is, the apparatus at either end of the line has been operated in unison with that at the other end. In most synchronous systems of telegraphy, synchronism is obtained by adjusting the apparatus at each station so that it rotates very closely to some predetermined speed and in some way, at definite intervals, a correcting impulse is sent over the line; by this means the position of the apparatus is changed by the amount it has deviated from the other machine since the last correction. All methods of synchronism based on this principle have proved that they require extremely delicate adjustment, and even under the best conditions are subject to frequent disturbances.

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* Recently a double-needle indicating instrument has been devised for use in connection with the Rowland system; one needle indicates when the resistance referred to has been properly adjusted, and the two needles by both giving zero readings indicate when the capacity has been adjusted and located.

The synchronism as used in the Rowland system of telegraphy is of a continuous and stable character. The synchronism is maintained by the use of every impulse which comes over the line, (of which there are in the octoplex 196 per second) and not a small fraction of the total number, as in the case of the systems referred to above. These impulses come at such a rapid rate that on account of the large inertia of the moving parts no effect is observed due to each impulse separately; but the regulation is entirely due to the integral effect of a large number of impulses, so that any variation of even a comparatively large number of the impulses will produce no sudden disturbance of the synchronism.

POTTS' SYNCHRONIZER

This synchronizer (which is the form now used on the Rowland machines) consists of a small direct-current shunt motor, (See Fig. 7). On a shaft driven by this motor is mounted a trailer Z_b which passes over a crown commutator having alternate segments electrically connected. This crown commutator has such a number of segments that each segment corresponds to a half wave of the alternating current used for signalling. It will be seen that the effect of this brush arm and commutator is identical with that of the vibrating tongue of a relay. The alternate segments of this crown commutator are connected to the two contacts of the synchronizing end of the main-line relay. In series with the armature of the motor above referred to is a resistance Z_r. One side of this resistance is connected to the synchronizing tongue M_{st} of the main-line relay. The other terminal of this resistance is connected to the trailer Z_b.

The tongue of the main-line relay is kept in continuous vibration by the alternating current from the distant station, and the trailer Z_b is kept in continuous rotation by the motor. If the tongue of the relay is on the side contact which is connected to the set of segments of the crown commutator which the trailer is touching at the same time, it will be seen that the resistance Z_r is short-circuited; while if the tongue of the main line relay is on the side contact of the relay which is not connected to the set of segments of the crown commutator which the brush Z_b is touching at the same time, the resistance Z_r will be in series with the armature of the motor. In one case the armature will receive a much greater current than in the other.

Consider, first, the case when the vibrations of the tongue of the main line relay and the rotation of the brush arm bear such a relation to one another, that as long as the tongue M_{zt} is against the contact M_{zc_1} the brush Z_b is in contact with the segments Z_{s_1}. If this condition is maintained it will be seen that the resistance Z_r is continuously shunted.

Secondly, consider the case when the vibrations of the tongue of the main line relay bear such a relation to the rotation of the brush arm, that when the tongue M_{zt} is on the contact M_{zc_1} the brush is on segments Z_{s_2} and when the tongue is on the contact M_{zc_2} the brush is on the segments Z_{s_1}. If this condition is continuously maintained it will be seen that the resistance Z_r is continuously in circuit with the armature.

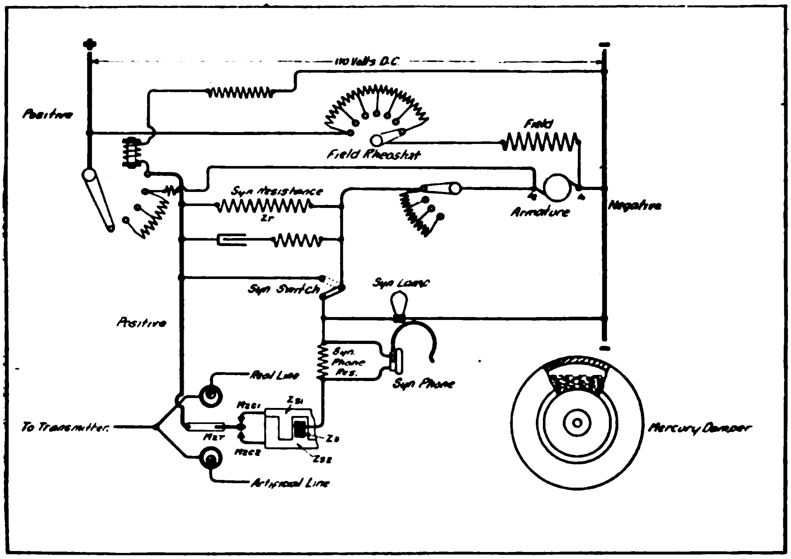

Fig. 7—Synchronizing connections

Thirdly, consider any case in which the vibrations of the relay tongue and rotation of the brush arm have some relation between the above two. If any relation between the first two mentioned is continuously maintained, it will be readily seen that at rapidly recurring intervals the resistance Z_r will be in circuit and out of circuit. Depending upon the relation between the vibration of the tongue and the rotation of the brush arm, the intervals during which the resistance is in circuit and out of circuit will vary in length; and in addition to the regular current flowing through the armature, there will be a pulsating current flowing through the same and the strength of these impulses will depend upon the relation existing between the vibrations of the tongue and the rotation of the brush arm. Consequently, while the relay tongue is vibrating in unison with the rotation of the brush arm, there can be various amounts of current flowing through the armature of the motor, depending upon the relation of the relay tongue and the brush arm. (This relation is spoken of as the phase difference).

Let us assume that the relay tongue and the brush arm have such a relation that the current allowed to flow through the armature is of the correct value to maintain the speed of the motor at the same value continuously. If the rate of vibration of the relay tongue increases, the relation between the vibration of the relay tongue and the rotation of the brush arm will change, but in such a manner as to strengthen the impulses flowing through the armature; and consequently the speed of the motor will be increased, but only until this speed corresponds to the rate of vibration of the tongue. If the armature of the motor attempts to go faster than the vibrations of the relay tongue, the impulses through the armature are weakened and the speed is kept normal. If the motor attemps to go slower the impulses are strengthened and the speed of the motor is still kept normal. Consequently the speed of the motor follows any changes in the vibrations of the tongue and any tendency for the motor to change its speed, as, for instance, a change in the voltage in the power circuit, is immediately compensated for by a slight shift in the phase difference above mentioned. In starting the machine, synchronism is obtained by the use of a rheostat in series with the motor field.

The operation of the synchronizing device will be better understood by referring to Fig. 4 which gives several oscillograms of the synchronizing current under different conditions. Curve No. 3 is the current through the motor armature when in synchronism, and Curve No. 4 is same when the motor is coming into synchronism. Curve No. 5 shows the current furnished to the motor by way of the vibrating relay and not the total current in the armature of the motor and for a high value of current in the field of the motor. Curve No. 6 is the same as No. 5

except that a much smaller value of current is flowing in the fields of the motor. In both Curve No. 5 and No. 6 the motor was in synchronism. The difference in length and value of the impulses in the two cases is to be noted. Curve No. 7 shows the same current as No. 5 except for the condition when the motor is coming into synchronism. The rheostat is regulated until synchronism is obtained.

If the above arrangement is used alone, it will be found that the synchronism will not be steady, but will oscillate; that is, at rapid intervals the speed of the motor will increase and decrease between certain limits. These oscillations are prevented by mounting on the high-speed shaft of the motor a so-called viscous damper. In one form this damper consists of a steel fly-wheel having a hollow rim which is nearly filled with mercury. The friction between the rotating mercury and the rotating rim of the fly wheel rapidly dampens any vibrations which tend to take place and makes the synchronism almost, if not quite, dead-beat. This effect of the mercury damper is identical with the effect produced on the vibrations of a pendulum by immersing it in molasses or mercury.

In regard to the practical operation of the above method of synchronism, it may be stated that the synchronism is often maintained for a whole day continuously without a single failure. Line swings of short duration do not cause it to loosen the letter, but cause an oscillation for an instant. All the variations of voltage, etc., under commercial conditions are automatically taken care of. To illustrate, in a test of this point changes in the conditions, which would cause the motor to change its speeds 50% if the synchronizing device were cut out, have been made without loss of synchronism.

SYNCHRONOUS INDICATOR

In addition to being able to produce synchronism, it is necessary to have some means of knowing when synchronism has been obtained. There are many methods of doing this. Two methods are usually provided.

First. The synchronizing telephone.

This is a telephone in parallel with a small resistance, through which flows a small part of the pulsating current which flows through the armature of the motor. If synchronism has not been obtained, sounds of two different pitches will be heard in the telephone. If the speed is sufficiently near synchronism beats will be heard, similar to those produced when two keys of nearly the same pitch on an organ are sounded at the same time. As the speed more nearly approaches synchronism these beats will follow each other at greater intervals; and finally, when synchronism has been obtained, there will be a smooth sound of a definite pitch.

Second. The synchronizing lamp.

An incandescent lamp is connected so that it receives a pulsating current similar to that passing through the armature of the motor and the telephone. When synchronism has not been obtained the light of the lamp will pulsate; when synchronism has been obtained the light of the lamp will be steady.

FINDING THE LETTER

It will be noted from the description of the synchronizer that every alternate segment of the synchronizing commutator is in electrical connection, and that consequently when synchronism is obtained the brushes may be on any one of 28 segments in the octoplex, or on any one of 14 segments in the quadruplex. Before the signals can be received properly, it is necessary that the trailers of the sending and receiving stations shall be on corresponding segments.

The operation of shifting the brushes so that they are on corresponding segments is the so-called " finding the letter." For this purpose, at the sending station the impulse corresponding to the fifty-fifth segment (in the quadruplex it is the twenty-seventh segement) is reversed every revolution. At the receiving station the fifty-fifth segment in the octoplex, or the twenty-seventh in the quadruplex, operates the "letter finder " relay, identical in connections with a selecting relay. This relay is so connected, that when it receives a normal unreversed impulse it is against its rear contact; but when it receives a reversed impulse it is against its front contact.

A gear driven by the motor pinion on the line unit, at a speed of 3.5 revolutions per second—the normal operating speed—carries a pawl which engages with a 28 toothed ratchet; in the quadruplex the ratchet has 14 teeth. This ratchet is fixed rigidly on the gear which drives the commutator brushes. The motor pinion, then, drives the gear carrying the pawl, and the pawl engaging the ratchet drives the train of gears carrying the brushes on the commutator. An electromagnet attached to the frame of the machine operates a plunger which causes a pin to trip the pawl on the ratchet, dropping it back one tooth each time the magnet is operated. The circuit of the magnet is completed through a resistance, a push button, and the back contact of the letter finder relay.

If synchronism has been obtained and the brushes are not on corresponding segments at the sending and receiving stations, the letter finder relay will be back, and when the push button is depressed the letter finder magnet will operate and the pawl will drop back one tooth in the ratchet each revolution until the brushes are on corresponding segments, when the reversed fifty-fifth impulse will fall on the letter finder relay, and the circuit of the letter finder magnet will be broken. An incandescent lamp is connected from the positive terminal through the back contact and tongue of the letter finder relay to negative. As long as the brushes are not on corresponding segments this lamp will be lighted. When the brushes are on corresponding segments, and the relay tongue is therefore on its front contact, the lamp will go out indicating that the letter has been found.

TRANSMISSION OF THE SIGNALS

The transmitting apparatus proper consists of a keyboard, a sending commutator, and a transmitting relay. (See Fig. 8.) The keyboard consists of a number of levers, one for each character, pivoted in the middle and each carrying a heavy contact strip which, when the key is depressed, makes contact with two pins. On one end of this lever is a small lip S_2 which engages a steel bar S_1, passing above the keys. By means of a cam S_4 and a lever S_3 this bar is given a reciprocating motion. In one position it permits the keys to be depressed at will, and in the other position it holds the keys down or up, as the case may be. At the usual speed of operation this bar is made to oscillate three and one-half times per second.

The sending commutator consists of a ring dvided into 56 segments in the octoplex, or 28 in the quadruplex. Each of these segments corresponds to a half-wave. Eleven segments being connected to each keyboard, each key when depressed connects two of these segments to the negative.

The transmitting relay consists of a polar relay of ordinary form, one coil of which is connected through a high resistance in such a way as to receive current continuously, giving the transmitter tongue a bias which holds it normally against one contact. The other coil when energized by current through the sending commutator, keyboard contact pins and key lever, and a resistance, attracts the transmitter tongue to the other contact. This disconnects the line from one secondary of the transformer and connects it to the other, thus sending an impulse the reverse of the normal. When the brush passes over such segments as are made negative by a depressed key on the keyboard, the magnet S_M is energized, and the impulses corresponding to these segments are reversed. The cam S_4 is so geared to the brush S_b that the keys are always locked when the brushes pass over the segments corresponding to that particular keyboard.

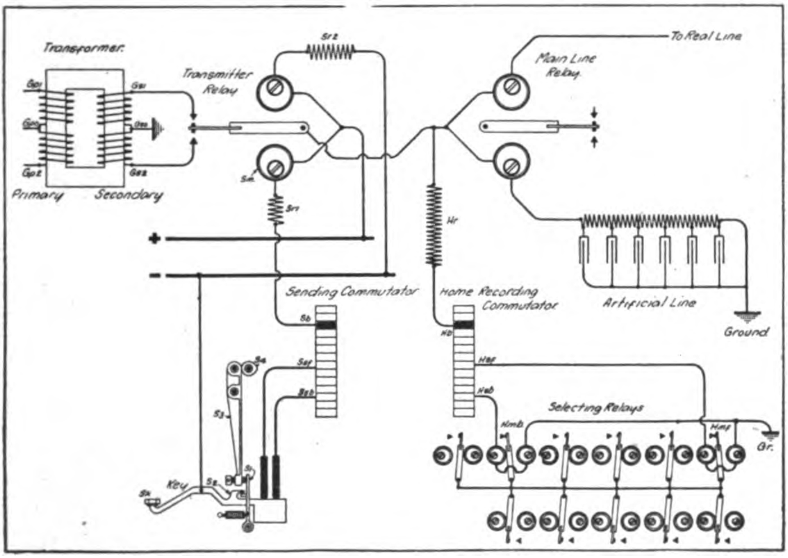

FIG. 8—Transmitting and home-recording connections

HOME RECORDER

In addition to printing the message at the distant station, a record is also obtained at the sending station for the guidance of the operator and for record purposes. This record is produced by the outgoing signals, in a manner similar to that used at the receiving station. For this purpose each sending position is supplied with a bank of home-recording selecting relays identical with those supplied at the receiving position. These relays, instead of being operated by a current from the contacts of the main-line relay, are operated by a current shunted off from the main signalling current just before it enters the main-line relay. This signalling current is distributed to the various home-recording selecting relays by a commutator of 56 segments (or of 28 segments in the quadruplex) identical in construction with the receiving commutator.

The home-recording printer, in the present form, is a tape printer. The operation of this tape printer is perfectly identical with that of the page printer, except that the mechanism for lining, blanking, and backing is omitted. (See description of page printer). Corresponding to the back contact signal on the page printer at the distant end, there is placed on the sending tape printer a small incandescent lamp which lights whenever the receiving lamp relay is against its front contact; that is, whenever the carriage on the page printer is within a certain number of letters of the end of a line, notifying the sending operator of this fact.

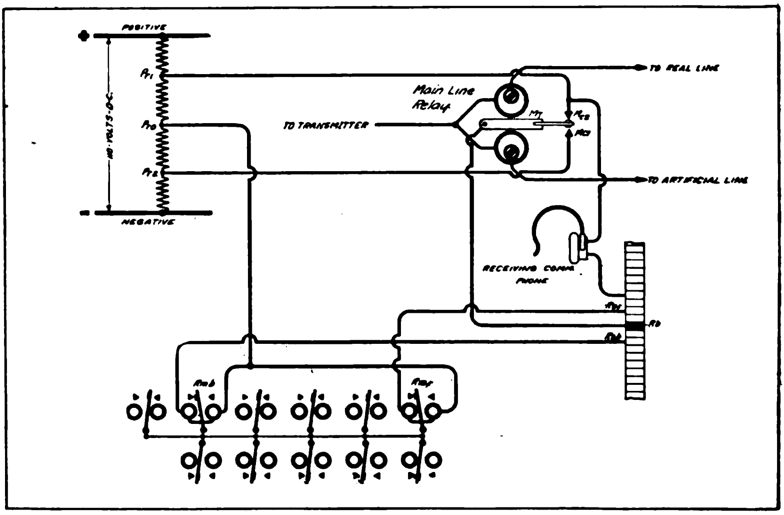

Fig. 9—Receiving connections

Receiving the Signals

On account of the fact that the signals are produced by a combination of two out of eleven, it is necessary that the first of the two signals received be stored up in some way until the second signal is received, before the corresponding character can be printed. This is accomplished by the use of polarized relays, one corresponding to each of the eleven impulses. Each printer is furnished with a bank of 11 receiving selecting relays. (See Fig. 9.) For receiving the signals there is employed a vibrating tongue of the same line relay which is used for synchronizing, the relay having two independent tongues and pairs of contacts, one for synchronizing and one for printing.

The receiving, like the sending commutator, consists of a ring divided into 56 segments in the octoplex, or 28 segments in the quadruplex, one segment corresponding to each of the 56 or 28 impulses. One terminal of the winding of each relay is connected to a common point, and the other terminal to the corresponding segment of the receiving commutator, so that each relay represents one of the 56 or of the 28 impulses. Every alternate relay is connected in reverse, so that as the alternating current is distributed among the relays, each one is against its back stop, except in the case when the corresponding impulse is reversed, when the relay tongue will be against its front stop.

A resistance of 600 ohms is shunted across the 110-volt direct-current mains. The middle of this resistance is connected to the common terminal of the receiving selecting relays. The print contacts of the main-line relay are connected to points about 100 ohms from the terminals of the 600-ohm resistance. As the tongue of the main-line relay vibrates from one contact to the other, the current furnished the selecting relays changes its direction, and reproduces locally the signalling current received from the other station. As the brush R_b rotates in synchronism with the vibrations of the tongue M_T, each of the selecting relays will receive an impulse which will draw the tongue against its back or front stop, depending upon whether the impulse has been normal or reversed at the sending station.

Fig. 4, Curve 2, shows the impulses flowing through the selecting relays. The impulses shown correspond to those for the received current shown in Curve 1.

A telephone will be noted on Fig. 9. This is for the purpose of indicating the proper adjustment of the receiving commutator. When the commutator is not properly adjusted it is indicated by a loud rap in the telephone.

AUTOMATIC TRANSLATION OF RECEIVED SIGNALS INTO PRINTED CHARACTERS

The page printer, by means of which 51 different operations may be performed from the keyboard controlled by the operator at the distant station, involves the following features:

First. A solid steel type-wheel about 2.5 inches in diameter, on the circumference of which the characters to be printed are engraved. This type-wheel revolves continuously at the end of a horizontal shaft, and in synchronism with the trailers on the various commutators.

Second. A light paper carriage, carrying the paper which is fed from a roll underneath the type-wheel when new lines are to be made.

Third. A device to thrust the paper forward to make a new line.

Fourth. A device to move the paper carriage sideways to produce the space between letters and between words.

Fifth. A device to return the carriage to the beginning of a new line.

Sixth. A small printing magnet, which operates a hammer or platen which throws the paper against the lower side of the rim of the type-wheel, at the moment when the character to be printed has turned to its proper position above the line.

Seventh. A set of five polarized relays called the distributing relays, connected to the page printer by a cable, which serves the purpose of making contacts at proper moments for sending current to the print magnet to print; to a lining magnet to line; to a spacing magnet to move the paper sideways; to a backing magnet, which allows the carriage to return for the beginning of a new line; and to a blanking mechanism which rapidly feeds out the paper until a new blank is in the proper position for the beginning of a new message. Each of these operations is completely controlled by a key on the keyboard at the distant station.

Eighth. A combination commutator, the function of which will appear from the following description. Fig. 10 shows such a commutator developed. This commutator consists of three rings being divided into a number of segments, one fifty-sixth of a circumference corresponding to each operation. The rings 1 and 2 are divided into various segments lettered from A to K. The arrangement of these segments are so chosen that at one point, and only one point, any two segments corresponding to a given character will be in line. The third ring is divided into various segments, and according as the combination at any particular point of the commutator is to print, space, etc., this segment of the third ring is connected to the corresponding distributing relay. All of the segments in rings 1 and 2 bearing the same letter are connected to the contact of the corresponding receiving selecting relay, in the bank of eleven selecting relays belonging to that page printer.

The operation of the page-printer will be readily understood by reference to Fig. 10, where the connections of the page-printer are shown. The incoming signal, which consists of two reversed waves, is first received, as elsewhere described, by throwing forward the tongue of the two corresponding selecting relays against their front contacts. By so doing, the segments of the combination commutator having the same letters as these relays will be connected to the frame of the bank of selecting relays, since the eleven tongues of this bank of relays are electrically connected to the frame. The brush bearing on ring No. 2 of the combination commutator is connected directly to negative, the frame of the machine, while the brushes on rings No. 1 and No. 3 are insulated from the frame, but connected to each other.

When the trailer brushes on the combination commutator, being in continuous rotation on the three rings Nos. 1, 2. and 3, rest at the same time upon segments of the commutator which are connected together, through the contacts and tongues of the two selecting relays which are against their front stops, an impulse will be sent through the wire *P* 12 and the front spool of the print relay. This will throw the tongue of the print relay forward and close the circuit of the print magnet, operating the hammer and throwing the paper against the type-wheel at the proper time to print the letter corresponding to the signal sent.

When the print magnet operates, a contact on the hammer will ground the contact 5, and thus send a current through the back spool 13, of the print relay, and also through the front spool of the space relay. This will open the circuit of the print magnet, thus releasing it, and at the same time will close the circuit of the space magnet. When the space magnet has operated the spacing mechanism of the printer, a contact attached to this mechanism connects the contact 7 to the negative, thus sending an impulse through the back spool *P* 7 of the space relay, and pulling the tongue of the space relay against its back contact, thus opening the circuit of the space magnet.

The electrical operation of the backing mechanism is similar to that of the printing and the spacing , except that the operation of the release contact is somewhat different. In order to throw the backing relay against its back stop, it is necessary to make two contacts. One of these contacts, 9, is made when the paper carriage has returned to the beginning of a new line, so that current continues to flow through the back magnet until the carriage is returned to the beginning of a new line. The other contact, through wire, No. 23, is made by the trailer brush passing over a short segment on the combination commutator. The " buffer " magnet is energized by current through wire No. 14 and a contact on the plunger of the backing magnet, as soon as the backing magnet is operated. When the carriage returns to the beginning of a line it is held by the buffer magnet, which prevents the carriage rebounding, until, at the next revolution of the trailers, contact is made on the short segment of the commutator, and current through wire No. 23 and contact No. 9 and the back spool of the backing relay opens this relay and releases the backing and the buffer magnets.

The electrical operation of the lining mechanism is identical with that of the printing and the spacing. When the operator has finished a telegraphic message and desires to start a new one, the blank key is depressed. This throws forward the blanking relay against its front contact. This connects the front spool of the lining relay to negative by way of contact 16 and the blanking relay. The contact of the lining mechanism normally rests against the contact 16, and if the blanking relay is front the lining relay will be thrown front, and the lining magnet will operate and in so doing will ground the back spool of the lining relay through the contact 11, thus opening the circuit of the lining magnet, which will allow the negative contact of the lining mechanism again to throw front the lining relay. This process will continue and the paper will be fed out as long as the blanking relay remains forward. However, at definite intervals the paper is perforated, and as soon as the blank has advanced to the proper position the holes allow the brushes 17 to make contact through the paper with a negative connection on the frame. This sends an impulse through the back spool of the blanking relay, thus pulling the tongue of the blanking relay against its back contact and thus stopping the operation of the lining mechanism.

When the carriage is within a certain number of characters of the end of the line, a contact is made by the action of a strip on the carriage frame, thus grounding the segment on the sending commutator which corresponds to the back signal. This continues to send the backing signal to the operator at the distant

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end as long as the carriage is within a certain distance of the end of the line. This is also so arranged that when the blanking relay is front and the paper is feeding out, it sends the signal to light the red lamp at the sending station, thus insuring that the sending operator does not begin a new message before the paper has stopped moving.

MECHANISM FOR PRODUCING THE UNISON OF LOCAL APPARATUS

In order that the motor which is synchronized by the impulses over the line, and which drives the brushes on the commutators directly concerned with the sending and the reception of signals, have as little and as constant an amount of work to do as possible, the printers and home-recorders are sometimes (particularly in large installations) driven by a separate motor, Fig. 13, which is kept in unison with the motor on the line unit. It is not only necessary that these two pieces of apparatus be kept in synchronism, but also that their commutators bear a definite relation to one another. In order that this may be the case, the mechanism which maintains the unison of these two pieces of apparatus is so arranged that this unison is possible only when the commutators bear a correct relation, the one to the other.

On the line unit is a commutator, known as the multiple-unison commutator, divided into twelve segments; and on the unison unit, which is the driving mechanism of the local printers, is a similar commutator of 12 segments, known as the unison unit commutator. The corresponding segments on these two commutators are electrically connected. The brush on the multiple-unison commutator is connected to negative. The brush on the unison-unit commutator is connected—after the unison-unit motor is brought up to speed by means of the starting box—to one terminal of the motor armature, and also to one terminal of the synchronizing resistance. The other terminal of the synchronizing resistance is connected to negative: and the other terminal of the motor armature to positive. The brushes on the unison-unit commutator are driven by the unison-unit motor.

When the line-unit and unison-unit motors are running at the proper speed the brushes on each commutator will be making 210 revolutions per minute. If the brushes are on corresponding segments of the two commutators, the synchronizing resistance will be short-circuited, and the armature of the unison-unit motor will be directly across the power mains. If the brushes are not on corresponding segments of the two commutators, the synchronizing resistance will be inserted in the armature circuit, reducing the speed of the unison-unit motor, which will run slowly until it has dropped back to a point where the brushes are again on corresponding segments on the two commutators, when the armature will again receive its full current. By adjusting the resistance in series with the shunt field of the motors, the speed can be regulated to such a point that the action of the brushes on the commutators, in short circuiting the synchronizing resistance, will keep the unison-unit motor in synchronism with the line-unit motor. It is of course not necessary to adjust this resistance every time the motor is started. This resistance is set for any speed of operation once for all. and the motor is then started just the same as any motor; *i.e.* by the use of a starting lever. The synchronism takes care of itself.

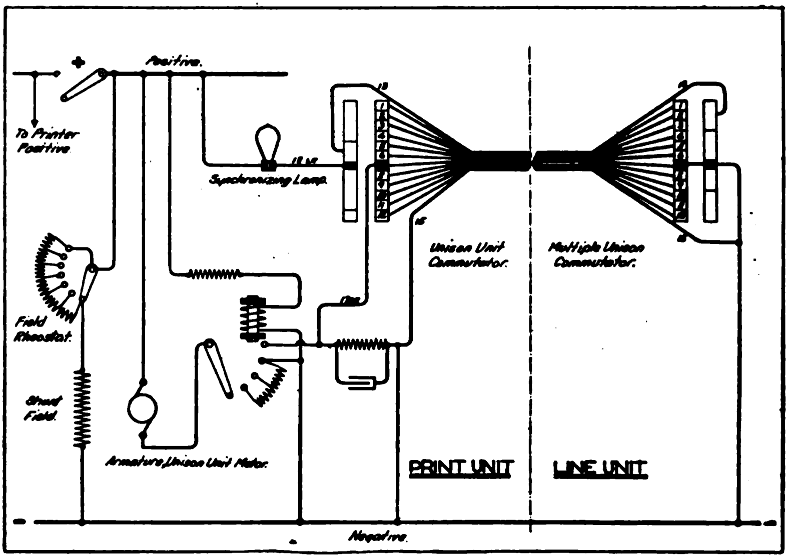

FIG. 11—Unison-unit connections

For the purpose of indicating when the two pieces of apparatus are in unison, a unison lamp is provided. The circuit of this lamp is completed through extra rings on each commutator. It will be noted by reference to Fig. 13, that this lamp receives no current when the two brushes are rotating in synchronism; but if the synchronism moves the distance of more than one segment, this lamp will receive an intermittent current and will thus indicate that the two pieces of apparatus are not in unison.

To secure a uniform rotation of the print-unit driving shafts, a mercury damper similar in action to that on the line-unit motor, is provided for the unison-unit motor. To assist further in obtaining as nearly as possible an absolutely uniform rotation of the type-wheel on the individual printers, so that the type-wheel will travel at all points in its revolution a fixed, definite distance between the time when the impulse is received by the print relay and the time when the platen strikes the paper against the type-wheel, and thus give uniform spacing between the letters, each type-wheel shaft is provided with a fly-wheel; and the driving dog on the end of the shaft, through which the motion is transmitted to the shaft, is made up by winding a flat steel spring into a spiral, one end of which is fastened rigidly to the shaft, and the other end of which engages the driving dog. The spring has a strip of heavy, non-elastic material wound with it, the action of which prevents rapid oscillations of the spring.

METHOD OF CONSTRUCTION OF APPARATUS

The Rowland apparatus is divided into a number of units for convenience of manufacture and operation. Any unit can be quickly removed and replaced by another unit. In general any machine is divided into three units, the line unit, the correspondence unit, and the unison-unit. (See Figs. 2, 3, 12, and 13.) The line unit comprises the current generator, sending, receiving, and home-recording commutators, synchronizing device, transmitter and main-line relay and all the parts directly concerned with the line, in other words the purely telegraphic parts of the apparatus The correspondence unit comprises the keyboard, home recording printer, and receiving printer; in other words, a duplex electrical type-writer. The unison unit simply serves to supply power to operate the correspondence units; it may be dispensed with in case of small installations, as they can be operated directly by the line, or a separate one may be provided for each correspondence unit if so desired.

CONCLUSION

From the foregoing discussion of the telegraphic situation and the description of the Rowland system, it has probably been understood already that the latter is constructed essentially to meet the demands of the former. A brief examination of the adaptability of the machine to the situation, however, is necessary in order to appreciate thoroughly its practical utility and efficiency.

The most important practical requirements of the telegraphic service are accuracy and promptness. These factors, in a great measure, determine for the telegraph its peculiar field. In the Morse system the presence of the human element in every operation necessarily introduces corresponding inaccuracies. In the Rowland system the human element is reduced to a minimum by keyboard transmission and automatic reception. The printed local record before the Rowland operator, too, shows what has been transmitted, and furnishes the operator an immediate method of checking the message sent. The octoplex wire capacity of the Rowland and direct transmission from typewriter keyboards with direct reception in printed characters on regular telegraphic blanks ready for immediate delivery constitute the best possible combination to insure promptness. With the Morse system, particularly in wet weather when the wire capacity is reduced, serious delays in transmitting telegrams often occur through a sudden or abnormal accumulation of business. The octoplex wire capacity of the Rowland system

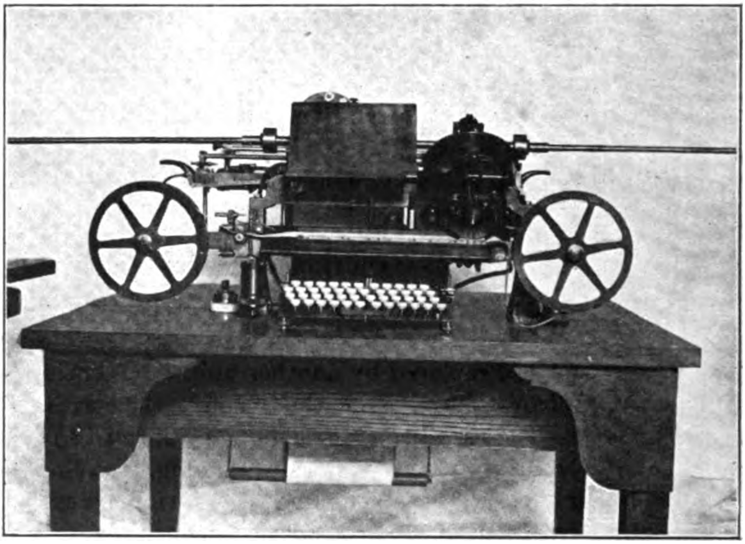

FIG. 12.—Correspondence unit, sending side showing keyboard and Home recorder.

in all weather conditions provides a greatly increased margin for reducing and avoiding such delays.

As already explained, the machine demanded by the telegraphic field must give greater efficiency to the operator and the wire than can be done with Morse methods.

The efficiency of a Rowland operator is practically double that of a Morse operator. To transmit a Morse message, two skilled operators are necessary, while to transmit a Rowland message one typist is necessary. The sole requirement that the operator shall be a typist and able to transmit a message intelligently greatly broadens the labor field and permits the economies incident to such an increased supply.

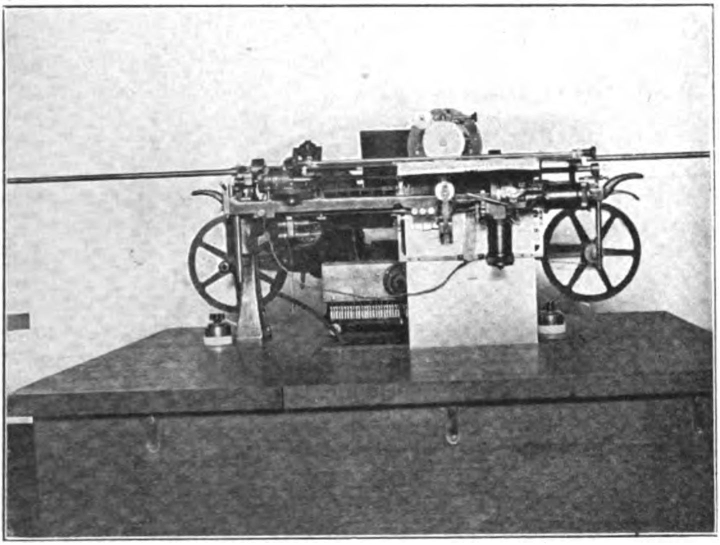

Fig. 13.—Correspondence unit, receiving side showing page-printer.

The more complete utilization of the wire operated by the Rowland, as compared with the Morse, has already been suggested. Under weather conditions most favorable to the Morse, the Rowland wire capacity is double that of the Morse, while in weather unfavorable to the Morse, the Rowland wire capacity is triple or quadruple that of the Morse.

As features of the Rowland system which lend themselves to further expansion and development in the telegraphic field, it is interesting to note that the method of dividing the use of a telegraph wire among a number of operators provides the fundamental and ideal requisite for the development of new and improved distributing methods for the general service and for facilitating and expanding the private use of the telegraph. Machine methods of relaying, more accurate and efficient in their operation than Morse methods offer further promising fields for greater efficiency.

In conclusion, having indicated the field and the demand for a machine telegraph and how the machine under consideration meets the conditions imposed, it only remains to suggest that with the application of machines, which provide for the more efficient transmission of a greatly increased business on present wire systems, and the further developments of the possibilities outlined, it is not unreasonable to expect that the telegraphic service directed by a broad policy will become in the near future hardly second in its unrestricted use and importance to the post office itself.

NOTE.--The above article has been written with special reference to American practice and in particular the highly developed American Morse methods and the highly skilled American operator. Many points of difference present themselves in foreign practice. It is possible elsewhere to use much smaller values of received current than here. The saving in wires becomes much greater when considered with reference to countries making use of other methods of transmission.

A paper presented at a meeting of the Boston Branch of the American Institute of Electrical Engineers, Boston, Mass., February 20, 1907.

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NOTES ON HYDROELECTRIC PLANT ORGANIZATION AND OPERATION

BY FARLEY OSGOOD*

In order to discuss the several branches of hydroelectric plant organization in logical sequence, it seems desirable to divide the subject into two general headings: physical and personal. The general heading physical organization may be more closely followed under the subdivisions: hydraulic, power station, and line.

Hydraulic Department

The first matter to consider on the hydraulic end of a system is the amount of water available for power. If the source of power is of such magnitude that only a portion of the available water is needed to fulfil the requirements of a proposed development, the study will be along different lines from a development which is to take the entire discharge of a river or reservoir system. Unfortunately for those interested in water-power possibilities, there are not many sources of supply which will satisfy the demands by the use of but a portion of the water obtainable. As the greater percentage of power developments require the use of the entire source of water supply, this paper will deal with such types of installation.

The department of Geological Survey of the United States government has accumulated a vast amount of data regarding stream-discharges, drainage-areas, etc., throughout the whole country, and there are few powers under consideration which are not at least partly covered by information easily obtainable and of great benefit to the investigating engineer. With government records in hand, a careful study of the surrounding country, of a possible site, should enable the investigator to determine the limitations of development. The inclination is to become over enthusiastic concerning a power study, which naturally leads to disastrous results, as it means, if followed too far, that an installation will be recommended greater than can be used to its full benefit continuously.

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*The writer desires to express his thanks to Mr. Frederick Miles for assistance in obtaining details of operation.

In this age of rapid development and performing of great engineering feats, we sometimes, perhaps too often, lack inclination to listen to our elders when they discourse on the happenings of their boyhood days; but when making a study of a water-power development it is good policy to make friends with the oldest inhabitant and his contemporaries, to draw them into tales of the terrible floods, awful ice jams, and droughts; for history repeats itself, we are told, and any recurrence of such happenings as may be related by our old friends of the region might blast forever the reputation of the power investigator, if proper provisions are not made to contend with these difficulties. The minimum and maximum discharge must be determined, and then the intermediate periods worked out to show the number of months in which the average or mean discharge is available for practical purposes. This is best shown by the plotting of curves based on calculations giving daily discharges; and the study should cover a period of as many years as can be covered by accurate information. The maximum discharge can seldom, if ever, be fully utilized; the minimum discharge must be guarded against; and the conservative mean discharge will be used as a basis for determining the canal section, sizes of water wheels, etc.—all, of course, to be considered together with the amount of fall obtainable.

Having decided that a water power will warrant development, the next step is to study the most advantageous location of the plant. There must be a dam; that is, when the entire supply is to be utilized, and the dam must be so placed and constructed that it can never be carried away by floods, ice jams, or other abnormal conditions. Generally speaking, dams of to-day are built of concrete, many solid, some rock-filled, and several hollow; in the latter type the concrete being merely a shell, as it were, reinforced with steel. The ideal dam location will have ledge for a base, and ledge to which to tie each end of the dam, but as this is by no means always possible, false floorings, deep-front cut-off walls, long wing-walls at the ends of the dam, and many other special features have to be resorted to for the sake of security.

If a sufficient fall is obtainable at the chosen dam-site the development will be a simple one, so simple perhaps that a portion of the dam may be used as one wall of the power station, thus enabling the engineer to make the least expensive designof a complete hydraulic plant. Usually a canal is necessary in order to get the full benefit of all possible head. This canal may be an open one, or a wooden or metal tube. When practicable, the open canal is the least expensive. Many developments necessitate a tube, especially in cases where the storage-pond is at the top of a mountain and the power station at its base. Wooden tubes reinforced with metal hoops are common throughout the Northwest, but eastern practice seems to favor the metal tube. If an open canal is decided upon, it is desirable to have a waste-gate arrangement ahead of the intake or controlling gates of the canal proper. This is especially true when the spillway of the dam is a short one, as sudden rises of a pond may be difficult to control; but if the location of the dam is such that the natural discharge-area of the pond or river can be considerably increased, the provision for wasting water ahead of the controlling gates is not really essential. If the development is to include waste-gates, a metal gate is preferable to a wooden one on account of its strength and greater ease of operation. A stop-log arrangement at the mouth of the canal cut will make it possible to dry the canal section ahead of the canal controlling gates, thus making it possible to make repairs to all the gates in the headworks. If waste-gates are used, it is a good plan to have one of them open from the top down, thus taking off surface debris, while the other gates should open from the canal bottom up, thus ensuring the abilitytodry the head works section when necessary.

If the canal is a long one, and especially if it is so situated as to become the drain of a hilly surrounding country, it is well to provide spillways along the canal, the top elevation of which should be lower than the elevation determined for the berm of the canal bank. Care must be taken properly to protect the canal bank at these spillway points, as any lack of control of this waste water might destroy the canal wall. At the lower or power-house end of the canal a forebay or small reservoir development is a good feature in order to steady the water at the entrance of the penstock or flume to which the water wheels are directly connected. If the canal is a long one and of such small cross-sectional area as to necessitate any appreciable velocity of the water, a forebay is practically indispensable, else sudden increases of load on the station will cause great discomfort owing to the inability to feed the water wheels fast enough. It is well, too, to provide the forebay with an ample spillway, as a final safeguard in times of flood occasioned by either natural or accidental causes. All the spillways along the canal and at the forebay should contain waste-gates in order to make it possible to drain the canal quickly in case of accident to any part of it. If a portion of the canal wall goes out, or even starts to fail, many thousand dollars may be saved by being able quickly to relieve the injured part of the water pressure against it. In a tubular canal care must be taken to provide secure anchorages at proper intervals, as there will be a constant tendency of the flume to slide downhill, although, of course, the weight of the water carried by the flume will greatly increase its frictional grip on the surface upon which it rests.

In either an open or closed canal development, trash-racks are necessary to keep floating substance out of the wheels. Trash-racks are usually made of metal slats, or metal bars, arranged in sections, and preferably designed in vertical sections as well. A rack-section should not exceed four feet in width; two feet is better. The rack-hoisting machinery should be housed, and the front of the building can be carried out over the racks with the front wall built down to form a curtain wall in the water ahead of the racks. This curtain wall acts both as a boom and as a means of sealing the building. It is best to heat the rack building during the ice season, as it will help to keep the racks free of ice, to say nothing of the comfort to the man in charge.

If the racks are built in vertical sections, properly pinned together, a rack can be easily removed by one man with the aid of a small differential chain-hoist which should be part of the rack-house equipment and designed to run on an elevated track placed so that the hoist may be brought directly over each rack-section. The vertical rack-section allows sufficiently light sections to be comfortably handled when out of position, thus greatly facilitating cleaning and repairing.

If the power station is not to be directly connected to the forebay, a penstock or flume will be necessary. This penstock must be protected against water-hammer occasioned by the sudden release of, or wide swings in, the load on the station, which would, by means of the water-wheel governors, shut off the passage of water through the wheels, thus leaving no outlet for the water at the lower end of the penstock. It can easily be seen that should this condition arise in a penstock of any material length without relief devices, it would not be unreasonable to expect the penstock to burst. This would bring about a calamity for which few engineers would care to be held responsible.

This water-hammer, or hydraulic ram effect, is overcome in two ways; first, by the use of a relief-valve near or at the lower end of the penstock, this valve to be set to operate at a pressure slightly higher than the normal operating pressure on the penstock; secondly, by the continuation of the penstock at its lower end to a perpendicular height equal to the elevation of the water-level in the forebay—the continued section usually to be of a somewhat smaller area than the main penstock. The latter, or standpipe method, is, of course, only practicable when the discharge from the top can be properly cared for outside the power station. Where the development necessitates the terminating of the penstock in or under the station, the relief valve is used with its proper discharge tube into the tailrace.

To guard against the rather unusual occurrence of having the penstock in danger of collapsing due to the water being suddenly taken from it, it is desirable to place one or more vent-pipes at the upper end of the penstock. The vent should be large enough to perform its duty when called upon, a fact not always appreciated by the designing engineer. The vent-pipe should be encased and kept from freezing. If a stand-pipe is part of the outfit, it should be encased and kept from freezing, and the surface-water at its top should receive sufficient heat to keep it open. The heating of the stand-pipe may be easily accomplished by either steam or electricity; it is best handled by having it included in whatever system is used to heat the power station.

It would at first seem proper to include the water-wheels in these notes on the hydraulic department, but as the wheels really form part of the power-station equipment, and are usually wholly or partly within the walls of the building, they will be considered under that classification.

POWER-STATION DEPARTMENT

As soon as the power station comes into consideration, it is necessary to go to the other end of the line and study the field of work to be fed by the station, as surely the nature of the load must determine the characteristics of the generating units. If the power development is to be one of any great magnitude, it will usually be designed to do general work including street and commercial lighting, electric railway service, and the factory power business—thus carrying a direct load, as well as a synchronous and inductive load.

Without question the current will be alternating. General practice favors three-phase current. As street lighting is apt to be a feature, the generating will be at a high number of cycles; 40 at least, and usually 60. Railway men prefer 25 cycles, of course, but that part of the load can be made a sub-station study. As these notes bear directly on the power and transmission end of the business, and as the time is limited, we will not consider the secondary end in this paper. After the character of the load is known, and assuming that three-phase, 60-cycle alternating current is to be furnished, the next step is to determine the transmission voltage.

The principal factor in determining the transmission voltage is the length of the proposed line. If the field of work is near at hand a low voltage maybe desirable, even as low as 10,000 volts, or in special cases 6600 volts. Under such conditions step-up transformers are unnecessary, for a machine voltage up to 11,000 volts is entirely within the limits of good practice. If, however, many miles of line are required, the transmission voltage should not be lower than 24,000 or preferably 33,000. Perhaps 50,000 or 60,000 volts would be better to meet all the conditions. As 33,000 volts is a very common transmission voltage, we will continue under the assumption that these notes bear on plants of that or a higher voltage, thus bringing in the necessity of step-up transformers.

Having learned the character of the load and determined the transmission voltage, it is now necessary to return to the water-wheels to find out what speed may be obtained from them. This, of course, will be determined by the amount of available head, and that factor will in turn determine the voltage of the generator units. As a rule, it is not advisable to have the generator voltage above 2300 volts, unless the generators are to have a very large kilowatt capacity, say over 2000 kw. The water-wheel and the generator must be considered together, for an arbitrary specification feature of one might well be beyond the mechanical or electrical possibility of the other. When generator requirements and water-wheel limits cannot be brought into a reasonably close relationship, then gears and belts have to be resorted to, and that is not desirable. Direct-connected work is the best, but an engineer should not ruin his station by impractical arrangements just to obtain direct-connected prime movers.

The available head is the first point of interest to the wheel designers, and secondly the flow of the stream. In low heads, and therefore moderate pressures, the wheels are sometimes placed in chambers in the forebay or headrace, the shaft running through the station wall, the generator being direct connected to it. When possible, this makes a very good arrangement, but provision should be made to shut the water out of these wheel-chambers, and also to drain these chambers in order to get at the wheels for inspection and repairs. As this arrangement of wheels will start with the opening of the turbine-bucket gates and draught-tube, it does away with the necessity of hydraulic-valve-operated gates, or in fact all other gates, which is greatly in its favor. In a fairly high-head development a penstock is required and the wheel-chamber scheme is impracticable.

In high-head work the wheels are usually inside the power station building and are encased in a large metal chamber used as a water-jacket. This arrangement will require some sort of a gate within the station, and it will be best to have the gates hydraulically operated, but care must be taken to have the operating device large enough to do its work unhesitatingly. It is well to have a second gate outside of the building in order to keep water out of the wheel-cases when the interior gate needs repairing.

A by-pass around the gate is essential in this type of wheel, in order to fill the water-jacket of the wheel before attempting to raise the interior gate, thus helping to equalize the pressure on each side of the gate, and greatly relieving the gate-raising equipment. This by-pass arrangement can be cast in the gate and controlled by a hand-operated valve. This scheme is preferable to a pipe and valve tapped into the intake pipe and wheel-case.

An electrically driven device can be used to operate these wheel-gates, the motor being driven by current from the exciters, thus putting the matter in the hands of the operator—a desirable thing in case of accident to a wheel requiring a quick shutdown. In very high head-work impulse wheels are used, the governors being used to deflect the stream from the nozzles rather than to open or close a gate equipment. There are many makes of good water-wheels in America, the choice is merely the decision as to the wheel best suited to the conditions at hand.

The water condition again becomes a factor when determining the capacity of the generator units, for it is desirable to have at least one unit which will be about equal to the minimum kilowatt output of the stream during periods of low water. It is advantageous to have all units of an equal capacity, but in low heads, with streams of great difference in minimum and average flow, this is often impossible. If all units are of equal capacity, it makes them interchangeable and thereby greatly reduces the stock of extra parts to be carried.

When, however, the average flow of a stream would warrant 2000-kw. units for general service conditions, but the minimum period would not develop over 500 kw., it is at once apparent that a 2000-kw. machine would give poor service during the low-stage period; for a machine works best when loaded, or nearly loaded, to its rated normal capacity. These points are to emphasize the fact that the hydraulic and electrical features must be considered together.

The most convenient arrangement of units is in a single row, and if possible on horizontal shafts with plenty of room between units for the water-wheel governors, and for the operators to pass comfortably between moving machines. Many a station is ruined by crowding the machines, and as water-driven stations are generally in rather isolated locations, the matter of land-cost is not an alarming factor, and, therefore, lack of room is inexcusable.

The exciting units should be of sufficient capacity to run the whole station with but one exciter. Motor-generator sets or electric-driven exciters are a good thing, as after the station is in operation the water-driven exciters can be shut down, thus saving water. There must be a water-driven exciter, or else the station cannot be started up. There should be two water-driven exciters, one reserved as a spare. It is possible to carry an exciter on the main shaft of the generator, usually on the outer end. In some cases each machine may carry its own exciter, one or two machines only may carry exciting units of sufficient capacity for the entire station. Belted exciters, from a pulley on a machine shaft, are sometimes used, but rarely in any but very small plants.

Individually driven exciters are without question the best type. An exciter driven by a larger unit necessitates the wasting of water. If for any reason the larger generator is unable to carry its portion of the load—and all machines require attention and repairs—the arrangement of each generator carrying its own exciter is a poor one, for if the water-wheel speed is affected, or the generator speed is momentarily changed by load fluctuations, then the exciter voltage follows the change. Frequently, then, the very opposite effect from the desired one is the result.

The location of the exciters is largely determined by the location of the operating switchboard, as the exciting machines should be in sight of the operator at the switchboard. The best location for the switchboard is on a gallery high enough from the floor to allow the operator to see all machines at once. The switchboard, if it does not extend the entire length of the gallery, should be in the centre; in such cases the water-driven exciters will be most easily observed if directly opposite the centre of the gallery, with the electric driven exciter, if one is used, on the gallery. If for any reason the switchboard must be on the floor, the exciters should be in sight from it; if the switchboard has to be at the end of the building, as is sometimes the case, have the exciters on the end instead of in the centre of the station.

Water-wheel governors give the best results when placed as near the wheels as possible; they should be electrically controlled from the switchboard, thus making it possible for the operator instantly to change the action of a governor. There are many types of governors, the foreign types being especially good for very large unit work, but there are American-made governors which are very efficient, giving entirely satisfactory results. American governors can be purchased for about half the cost of an equally good foreign make.

If the conditions will permit of a gallery, a very comfortable layout can be planned. The low-tension bus-bars are well out of the way, yet accessible, if placed overhead at the back of the gallery. If such an arrangement is chosen, it is a convenience to have each set of bus-bars at different heights from the floor, but not over one another. The low-tension bus-bars can also be well arranged if placed in hangers just under the floor of the gallery, although in this arrangement the switchboard wiring cannot be so well cared for, as proper bus-bar clearance must be provided.

Between the machines and the bus-bars there should be both knife-switches and oil-switches, the former to protect the latter, as sometimes an oil-switch fails to act properly. The oil-switches should be motor-driven, but the hand-operated oil-switches are cheaper and are safe for low-tension work.

All cables should be carried in ducts or troughs, and these conduits should be so arranged that they cannot retain water should any get into them accidentally. Where the cables are carried along walls, it is good practice to run them between cement panels, which oftentimes are enclosed except at the cable supporting points—where square holes are left—to enable the operator to inspect or change a support. The oil-switches are well located if placed under the gallery, though some operating engineers prefer them on the gallery directly underneath the low-tension bus-bars. Oil-switches are, of course, placed in individual chambers, often iron, and just as often brick or cement. It is not an unusual practice to close in the front of the chamber with a metal curtain, but by so doing the action of the switch is concealed. It is far better to have a thick-glass panel in the front of the switch-chamber, this glass to be set preferably in a metal frame. These frames can be built to contain a light of glass for each phase of the oil-switch, thus making it possible for the attendant to see the switch at all times, which is desirable both for mechanical and personal reasons.

A good position for the generator field-rheostats is on the gallery at the back, or immediately back of and above the switchboard. In any event, rheostats should not be placed under the gallery floor so that the heat from them will heat the floor of the gallery.

The switchboard is best located in the centre of the gallery and far enough back to enable the operator to pass in front of it without danger of his clothing coming in contact with any apparatus on the board, so he can safely turn his back on the switchboard when he is watching the action of the equipment on the floor of the station.

The voltage-regulators can be placed on a panel in the switchboard, preferably on or next to the exciter panels, or they can be hung on supports at the end of the switchboard.

The synchronizing device should be placed so as to be visible from the governor of every unit. In long stations two synchronizing indicators are desirable, being hung to swing at each upper corner of the switchboard.

Automatic line devices are essential, and excellent results are obtained by the three-phase bellows type time-limit overload relay, the same to close the circuit on the motor operating the line oil-switch, thus opening the line. The device itself can be placed on the back of the line panel of the switchboard, but the transformers for the relays should be placed immediately back of the low-tension side of the step-up transformers. This placing of these relay transformers is particularly desirable when there is more than one transmission line and the lines are operated in parallel.

If the relay transformers are not placed on the line side of the oil-switch, especially the paralleling-switch, there will be a flow of current through the paralleling-switch, which will at times make the relay fail, or at least so delay action that its service is too late, often causing uncomfortable results.

Many engineers prefer to have the high-tension chamber of a development in a separate building; this is not necessary, but the high-tension room should be entirely separated from the operating room by a heavy fire-proof wall, either brick or concrete. A suitable layout of the high-tension chamber of a power system is of great importance, the chief requisite being plenty of room. In three-phase systems, single-phase step-up transformers should be used, and the oil-filled water-cooled type is the best. The equipment connected to the high-tension end of the system and to the transmission lines receives the greatest insulation strains, and an oil-filled water-cooled transformer has a much higher insulation breakdown point than an air-blast transformer.

If the transformers are subjected to abnormal pressures, as in the case of lightning storms, surges, etc., it is unusual to have more than one fail, as the very failure discharges the disturbing high pressure; therefore, if single-phase transformers are used, the station loses the capacity of but one-third of the bank, and if spares are not available, the remaining two transformers may be re-connected and put into service. If three-phase transformers are used, much inconvenience may result from a breakdown. Single-phase transformers are more costly than three phase, but the money is well spent.

The cables from the line oil-switches will terminate in some sort of a bus-bar arrangement, to which will be connected the low-tension leads of the step-up transformers. These bus-bars should not be supported on hangers fastened to the transformer cases, but should be placed on the wall back of the transformers or one on a separate bus-bar supporting frame.

The terminals of the transformer leads should be split or of some quickly detachable type, or else much time will be wasted in getting an injured transformer out of service and making the re-connection of the remaining two of the bank.

A hoisting crane is a dangerous thing in most high-tension rooms, and therefore it will be a convenience to have a flush-track under and in front of the transformers. The transformers can be jacked up on to a low truck which will run on the tracks, or each transformer may be equipped permanently with wheels to run on the track.

As the failure of a step-up transformer is really a serious matter, and as such an accident may occur at the time of a peak load, it is good insurance to carry an extra bank of transformers, the same to be ready for service and arranged to be cut in merely by the throwing of a set of switches. A single transformer as a spare is of course better than no spare at all, but the spare bank is the true solving of the problem.

Between the step-up transformers and the high-tension bus-bars come the multiple-switches, or the switches so connected as to make it possible to cut in any bank of transformers on any outgoing line. These switches are usually knife-switches, although in very large developments high-tension oil-switches are used. For most purposes the knife-switches are sufficient, as the transformer bank is killed by the oil-switch on the low-tension side. If many banks of transformers are used, or if there are several outgoing lines, the connections between the multiple switches and the high-tension bus-bars may be much simplified by the use of sectionalized bus-bars. To the high-tension bus-bars are connected the transmission line, and these connections should be made through switches; knife-switches are sufficient. At first this may not seem necessary, but the induction effects from parallel transmission lines usually make these switches the best friends of the operators.

Just before the lines leave the high-tension room are the taps to the lightning-arresters. Some engineers prefer to have the protective devices in a separate building, but if the high-tension chamber is well arranged it is perfectly safe to install the arresters in it, and it is a good thing to have the action of the arresters observed by the operator. As the lightning-arrester problem is a study in itself, and as the writer is preparing some detailed information to be used at a future meeting, supplementing the paper given by him at the 1906 annual convention, it hardly seems wise at this time to get too deeply into this very fascinating subject. The arresters should be given plenty of room and should be installed so as to be quickly and easily handled, preferably within reach from the floor. If two or more transmission lines are used, it is good practice to have two complete spare arrester equipments, no matter what type of arrester is used.

Reactance or choke-coils in the line between the arrester taps and the high-tension bus-bars have been proved to be of great benefit, many a bus-bar insulator and transformer lead having been saved by their use.

Beware of the use of slate as a material for the hoods through which the lines pass in leaving the building. Glass is the best material. Simply a hole in the wall is sufficient, but it is desirable to be protected from the cold air in winter and also from small birds, who seem to feel that the power station is built for their special convenience.

Space, plenty of it, is the secret of good high-tension chamber design. If any crowding has to be done, let it be anywhere but in the high-tension room, or else forever keep away from the man who runs the station.

LINE DEPARTMENT

A few years ago the question of material for a pole line was scarcely given a thought, as wooden pole construction was a universal practice. Experience brought out the fact that the poles which lasted the longest were of wood indigenous to the locality in which they were used. Wooden pole lines through the south were subject to attacks from insects of various kinds, and the high voltages coming into favor set the wooden poles on fire when an insulator failed, and so metal poles became desirable and in many cases a necessity. Generally speaking, it is economical to-day to construct a metal pole line, and it is more satisfactory from an operating standpoint.

Metal towers vary greatly in price, as a simple tower consisting of a large iron or steel pipe guyed four ways will not cost over $70 placed, while a heavy angle-iron tower, or iron-pipe tower, built up in triangular or quadrangular formation, may cost $175 to $250 placed. The lattice tower built with foot plates to bolt to a concrete base can be made very costly when finally placed. The maintenance and depreciation charges against metal towers are very much lower than against wooden poles. The towers being stronger and usually somewhat higher, the section-lengths may be increased, thus making it possible to have fewer towers than wooden poles. This is a saving; it decreases the number of insulators required, and thus decreases the number of possible points of breakdown. The towers are virtually indestructible, and the fact that they ground the system in times of trouble is not a great detriment but is often a real benefit.

The question of copper or aluminum conductors is still an open one, there being many points in favor of each. There is not a great saving in the use of aluminum, as the market price is governed by the market price of copper. The electrical properties of aluminum, as compared with copper, make it necessary to have nearly twice the sectional area in an aluminum conductor, so, all things considered, the net financial result is not so greatly in its favor as is generally supposed. Copper is more quickly obtained on orders, but aluminum is more quickly put in place, as it is so easily handled on account of its lightness. Practice indicates that a copper conductor will remain intact at the point of an arc for a longer time than will aluminum, and while this is a good feature on a wooden line—it may burn off the cross-arm, and thus clear the trouble—it is impossible on a complete metal line, as there is nothing to burn off and a sustained ground on the line may bring failure elsewhere in the system.

At first it would seem that a modification of a metal line is advisable, and therefore a metal tower carrying a wooden cross-arm would be good practice; for with such a combination the system is benefited by the better pole, while it still retains the benefit of the destructible arm. As a matter of fact, the percentage of disturbances which burn themselves clear without causing a shutdown to that particular circuit is very low, and the metal arm and pins seldom require renewal. Reinforced concrete poles, both round and square, are being tried, but at present there are no definite data concerning them.

Where duplicate and parallel lines are built, the poles or towers should be so placed that the phase wires nearest each other on the two lines should be at least 25 ft. apart, thus giving plenty of room for a phase wire to break and fall without whipping into the other line.

Porcelain insulators have proved to be the best type for high-tension work, on account of their superior mechanical strength and ability to withstand great temperature changes.

A telephone line on the same pole line as the transmission line is worth its cost as a trouble indicator, as the telephone instrument bell reveals the slightest ground on the system. Such a line is likely to be heavily charged from the transmission line, making it very uncomfortable for the patrolman if he is careless in making his tap to it with his patrolling set terminals. This induction effect is, of course, relieved by transposing the high-tension wires. The telephone wires should be transposed about every third section. Although such a telephone line will show a surprising voltage between one side and the ground, it will be perfectly quiet, giving excellent transmission service.

A telephone service between the power station and the sub-stations on a pole line other than the transmission line is practically a necessity, as during times of trouble on the transmission line the telephone line on that pole line is put out of commission or is at least unsafe, and it is during times of trouble that the telephone service is most wanted. Often it is possible to obtain a private service from the public telephone company which will be less expensive, all points considered, than the fixed charges on an isolated private telephone plant.

ORGANIZATION OF EMPLOYEES

The organization of the operating force in an hydroelectric power system is less complicated than in a steam system. Fewer attendents are needed at the power station, for nature not only provides the element of power, but by the simple law of gravity brings it to and takes it from the station.

On the hydraulic end should be a man thoroughly acquainted with the physical features of the property he controls, for there are generally points in any development which need watching, and all maintenance work should be carried on without shutting down the plant. The canal or tubular flume, if the latter type is adopted, needs constant inspection, for leaks must be anticipated if possible, and preventive work started. The open seasons bring leaves, timber, and other debris into the pond and canal; the frost season has its terrors, for the effects of the force of frost are incalculable; and the winter seasons, especially in the New England and northern sections of the country, bring anchor-ice, frazil-ice, and sometimes great masses of ice—all of which do their utmost to overcome the efforts for continuous service. The intake gates usually have to be attended to, to meet the varying load conditions of the day, and as most plants are quite away from points of population, a maintenance force of laborers and teams has to be maintained.

There are so many different conditions of development and location in such systems that it is impossible to recommend any exact form of organization, as really no two can be quite alike. The power-station superintendent must of course organize his force to meet the exigencies of the service, but it is seldom that he will require more than three men on a shift, and, unless the station is of enormous capacity, more than two men: an operator, and an assistant can handle it, but this of course depends on the layout of the station. These station men must be clever mechanics, as usually skilled help is not quickly obtainable, and as it requires so few men to handle a station the system can afford to have a high class of operating attendants.

If the system is not too large it is desirable to have the station superintendent in control of the hydraulic superintendent, thus ensuring harmony between the departments, which is of vital importance. If a development is of such magnitude as to require the entire time of a superintendent for each of the departments under consideration, it will probably warrant some sort of a position for a man to whom both superintendents will report, thus still bringing the responsibility for the operation of the two departments under one head. The line department should have at its head a superintendent capable of building, repairing, and operating the lines; for if continuous service is to be maintained the various branches of the work are inseparable from an executive standpoint.

The patrolmen, or line inspectors, will probably have time to make all ordinary repairs, and the number required is determined largely by the length of the line, but particularly by conditions of accessibility. The line superintendent would naturally report to the general operating head of the system.

Some Operating Experiences and Requirements

The first requisite in an operating force is a thorough knowledge, on the part of each member, of the detail of the work in hand. These operators should be placed so that they can work to the greatest advantage to themselves, and hence to the greatest benefit of the employer. The adage, " You cannot fit a round peg into a square hole " is one which applies directly to an operating organization, for many a force of good and able individuals is ineffective simply on account of improper arrangement.

The second matter of importance, which is almost as essential as the first, is a spirit of good fellowship between all employees. This spirit is brought about chiefly by the feeling of individual responsibility and loyalty to the company or employer. The development of this spirit is in the hands of the chief of the operating department. If this feeling of individuality is properly developed, so that each member, no matter how low his position, feels that he is a spoke in the wheel of the necessary organization, wholesome rivalry and interest will be the result, the effect of which will be so great that the operating chief can accomplish many things in the line of good service, clear records, beneficial recommendations, etc., which without this feeling of coöperation would be almost impossible. The employee feels, and the employer should know, that this or that person is not obliged to work for that particular concern; but the employee should feel, and be made to understand, that so long as he does work for the concern, he does so with a smile.

The personal equation of an operating system is one to be solved before the final approval of the designs; by this is meant how much responsibility is to be placed on automatic operating devices. It is possible to work out a system so complete in its complication that one or two operators may control every detail of a plant. Such a scheme might be very advantageous when every part of the plant is running smoothly, and acting in an entirely normal manner, but unfortunately hydroelectric systems, like human systems, do not always run along without difficulties. In the good old days there were no automatic devices, and men took chances in operating plants that would be considered to-day as quite beyond the limits of good practice.

It is a safe plan to have a plant so arranged and equipped that in times of trouble the master mind may be relieved to the extent of having an assistant locate and cut out the disturbing element.

Some of the following actual operating experiences of the last few seasons, which occurred in the system with which the writer is connected, may be of interest. One employee of the hydraulic department, shortly after a talk with his foreman on the desirability of collecting all tools at the end of the day, was found on the canal bank stripped, and about half drowned. It turned out that he had dropped into the water an old 35-cent lantern, and was diving for it in moving water nearly 20 ft. deep, and without the slightest indication of success. After receiving word from his superior that under the circumstances he would be forgiven for losing the lantern, he confided that "the old lamp was not good for much anyhow."

When changing some switch connections, one of the men, having completed his work, found he could not let go of the wrench which he still had on a nut on one of the high-tension switches. The inductive effect from 60 miles of parallel circuit was so great that the system had to be momentarily shut down to release him. The line knife-switches as above mentioned would have prevented this occurrence, which fortunately terminated wthout permanent injury.

A lineman working on a part of the system which has iron arms strapped together and grounded, happened to touch his foot to the private telephone wire while coming down the pole, some part of his body evidently touching the ground wire from the cross-arms. Both transmission lines above were dead, but over twenty miles away the telephone line ran on a pole line which was carrying 33,000 volts on its wires, and although the telephone line is from 7 to 25 ft. from the transmission wires this man's actions and yells indicated as he shouted out, "This dead wire ain't dead," that he was correct. The man's body belt saved him from a fall, and after regaining his nerve he descended the pole, taking care not to serve as a jumper between the ground wire and the telephone circuit. The ground wire at this time had not been covered by moulding, as the work was not quite completed. This incident is cited simply to indicate the tremendous inductive effects in high-tension work.

All water wheels should be inspected at regular periods, and they should be so designed as to be easily got at and defective parts renewed. There seems to be an inclination on the part of many station men to neglect the inspection of the interior of water wheels, but broken gate-vanes, worn gate-blocks, cracked rocker-arms. and loosened governor-rod connections are some of the troubles likely to be found, even in a semimonthly inspection. If the hydraulic cylinder operating the water-jacket intake gate is so constructed as to seat tight on the floor of its chamber it will stick. Sometimes two hours of continuous working of the four-way valve will be required to unseat the cylinder and raise the gate. This is a real calamity if it happens to occur at the time of an approaching peak of the load, when perhaps all units will be needed.

Wheel design does not cause all operating discomforts, for in the fall season of the year it is not an unusual thing to find as many as thirty to forty eels in a wheel-case, all of which, as far as can be discovered, have been bracing their backs up against the gate to prevent its closing. Many small eels and fish get ground up in the wheels, and there is always a period of several weeks each year when the stench of dead fish makes the inspection of the wheels anything but pleasant.

Spring brings slush-ice, which is perhaps the greatest of all evils, for it stops up the bucket-gate openings. A shutdown is the only relief; then the wheel-cases can be opened and the snow-ice melted out. The strain on the operator during a slush-ice run is greater than during a lightning storm, for although lightning effects are furious, there is an end to them, while an ice run may last several days, and never for a shorter period than several hours.

Sticks in the wheel-cases are at times causes of great alarm, on account of the noise occasioned by their beating against the iron water-jacket; but experience seems to indicate that the greater the noise the less the danger, for such a stick is too large to get between the guide-vanes, and is therefore not especially harmful. In all such cases, when the unit can be spared, it should be shut down and the wheel-case cleared.

Duplicate water-feeds for cooling the step-up transformers are a comfort to the operator, for even if a screen is placed at the intake, material will accumulate and require removal. A large feed which can be opened at the lower end and flushed out makes a good arrangement if duplicate feeds are undesirable.

A screen at the intake of the feed-mains is essential, and if it is placed in a glass section of pipe it is always visible. It should be placed so as to be quickly removed for cleaning.

It is a good feature to have the water discharge pipe from each transformer carry a glass section, or be actually broken, so that the amount of water being discharged may be seen.

When a step-up transformer needs repair it is quite a task to get the transformer oil out of and back into the case; this may be done quickly by gravity if a suitable receiving tank is provided underneath the floor, and a storage tank at some point above the transformer.

Care should be taken to have the water-wheel governor oil-pump of sufficient capacity to make the governor act quickly. A small pump-plunger will cause sufficient delay in starting up a unit to inconvenience the attendant in synchronizing.

It is well to keep the inside wiring of the private telephone line which runs on the transmission line well away from all other wiring and any metal work. Four feet of separation would seem sufficient, but on a number of occasions during lightning storms, current crept along a cement wall for four feet, thus forming an arc between the private line and the long-distance line. Where the long-distance line passed around a column. the current jumped through the insulation of the wiring to ground; this arc was maintained for quite a period. On account of this experience, the private and long-distance telephone circuits were brought in at different parts of the building, and all wiring kept entirely separated. No trouble between the circuits has been experienced since.

The solenoid equipments of the time-limit relays should be taken apart and cleaned at least three times a year, otherwise they become gummed with dust in spite of all possible protection, and thus their time-limit effect is very much increased. These relays should be tested at least once a month to see if they are acting in accordance with the indicated overload and time limit.

The oil-switch motors and connecting clutches require constant cleaning, but when painted or varnished care should be taken to confine the coating to its proper location.

An oil-switch failed to release upon the closing of the circuit on its motor, and an investigation proved that one of the attendants in his zeal to do a complete and sufficient job of painting, had painted the end of the solenoid rod; the rod stuck just enough so that the magnetic clutch failed to release. The result was certainly undesirable.

Three times when an oil-switch clutch has failed to release, so that the switch opened and closed consecutively several times, the voltage dropped from 110 to 65, and notwithstanding the fact that all sub-stations were carrying 60-cycle synchronous machines in the form of synchronous converters they were not sufficiently thrown out of step to drop out. This seems almost incredible when we consider that 10% variation is the desirable limit for this type of equipment.

In operating transmission lines in parallel, reverse-current relays on the receiving end will save many a complete interruption.

Static voltage detectors prove a great help to the operator, as they not only indicate that a phase wire is alive but in case the wire becomes grounded the disk of the device will stop revolving. This little and inexpensive equipment, therefore, can be made to serve in a very important and helpful manner.

The single-phase ammeters on the outgoing lines, when their transformers are connected immediately back of the step-up transformers, serve as a very positive ground indicator, for the operator will notice the amperage increasing on an outside grounded phase wire, and sometimes this warning will give him sufficient time to get the line in trouble cut out without in any way interfering with the service.

Line insulators, generally speaking, will stand very severe insulation strains, but it is not unusual for an insulator to become slightly defective, although the full development of the defect will cause no trouble until some time later. This fact was brought out quite clearly during the last lightning season when the number of insulators damaged on the 60 miles of transmission line was so small as to cause comment; but in September, when the lightning season was practically over, a very dense fog enveloped the system for more than 36 hours, causing the failure of some six or eight insulators. These insulators were distributed over the entire length of the system.

The good will of its neighbors is one of the best assets a transmission company can have, but it is unfortunate when their good intentions are thwarted, as was the case when one of our neighbors seeing the top of a wooden line pole on fire brought out a large pail of water and his best force pump, and attempted to put out the fire. His surprise and humiliation were great when he picked himself up from under his front-yard fence on the other side of the highway from the pole in question.

EXPLANATION.

The following article is an "Introduction" to a discussion to take place at a special meeting of the INSTITUTE in the **Auditorium Hotel, Michigan Avenue, Chicago, Ill., Friday, May 24, 1907,** at 9 a.m. It is not intended to be a formal or complete paper, but to serve merely as a basis or framework for discussion on the subject with which it deals. All those connected with the Institute and desiring to take part in this discussion may do so by being present at the meeting, or if this is not possible by sending in a written "Contribution."

In contributing to a discussion, whether verbally or in writing, it is requested that the matter under discussion be taken up under the several subdivisions and in the order made use of in the Introduction, and that following the treatment of these subdivisions there be introduced any other matter which the contributor may deem advisable. When the contributions are made by mail on more than one of the topics under consideration at the same meeting, it is requested that the several contributions be embodied in separate letters.

Contributions will be read at the meeting for which they are intended either in full, in abstract, or as part of a general statement giving a summary of views of those taking the same position in the matter under discussion.

It should be borne in mind that the Introduction is written in order to provoke discussion, and that there should be no hesitancy in attacking if it does not agree with the opinions of the contributor. On the other hand, if the contributor agrees with the matter of the Introductions, either in whole or in part, he should state the fact.

It should also be borne in mind that the principal object of this scheme is to enable and encourage those not in a position to attend meetings to take part in a discussion. If one does not feel himself qualified to discuss certain parts of an Introduction, but is able to discuss other parts, it is to be hoped he will contribute to the latter.

Contributions to the discussion of this paper should be mailed to **Ralph D. Mershon, Chairman Transmission Committee, 60 Wall St., New York, N. Y.,** so that they will be received not later than May 20, 1907.

A paper to be presented at a Special Meeting of the American Institute of Electrical Engineers, Chicago, Ill., May 24, 1907.

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(*Subject to final revision for the Transactions*).

RELATIVE MERITS OF THREE-PHASE AND ONE-PHASE TRANSFORMERS

BY H. W. TOBEY

During the last few years there has been a gradually increasing tendency in this country toward the use of three-phase transformers on three-phase circuits instead of groups of three, or in some cases two, one-phase units. It is the purpose of this paper to outline briefly these two systems, and to point out as far as possible the important features of both, with their advantages and limitations.

In this country, particularly, there is a strong feeling among many engineers in favor of single units. This feeling is probably due in part to the feeling that if one transformer in a group gives trouble it can be readily removed and replaced by a spare, or if no spare is at hand the load can be carried by the remaining two, if delta connected; whereas if one phase of a three-phase transformer gives out the entire transformer is rendered useless. Where the plant is small, this feeling is more or less justified on account of the fact that an extra three-phase transformer, because of the additional expense, would be out of the question, whereas the cost of an extra one-phase transformer would not be serious.

Where the plant is fairly large, the saving in cost introduced by installing three-phase units makes possible the providing an extra transformer for reserve. Moreover, if no reserve is available it is possible, in the case of shell-type transformers at least, to take an injured phase out of commission and operate the remaining two phases in open delta until the necessary repairs can be made. This is done by means of an arrangement recently announced, in which both primary and econdary windings of the injured phase are cut out and short circuited on themselves. As mentioned, this method applies only to shell-type transformers connected delta primary and secondary.

From the foregoing, it would seem that as far as reliability is concerned the two systems are about equal.

As to initial cost, the three-phase transformer has a distinct advantage. Not only is it possible to utilize the iron in the magnetic circuit to better advantage, but a saving is also possible in the cost of the containing tank, inasmuch as only one is required instead of three. All things considered, the cost of a three-phase transformer may be taken as about 85% of that of three of the one-phase type—total capacity, frequency, and voltage being the same of course in both cases.

In addition to the initial cost, there is also a saving in material and labor incurred in connecting up the transformer for service. With the three-phase type, all interconnections between phases are made within the containing tank or case, thus leaving but three high-tension and an equal number of low-tension terminals with which to connect outside lines. For installation, therefore, the total amount of cable required is less, the connections are simpler, and consequent danger of error less with the three-phase transformer than with several one-phase transformers. The expense of isolating compartments is also much reduced, it being customary in many plants to provide a separate berth for each unit.

While general appearance is not necessarily a controlling feature in a transformer building, it is nevertheless to be considered, and here again the three-phase transformer with its simple connections would look neater and more symmetrical than would three one-phase units.

Floor space and height are features which in stations of limited area require careful consideration. In these regards the three-phase transformer has distinct advantages, as a saving of at least 30% can be attained in floor space. and usually its height is somewhat less than that of the one-phase unit.

As regards regulation, neither system can claim an advantage. Both regulate equally well on balanced and unbalanced loads, whether these are inductive or non-inductive.

In some plants the question of limited facilities for handling would be a deciding factor. Here then the choice would be in favor of one-phase units, on account of their decreased weight and dimensions.

For extremely large three-phase units it is probable that some system of forced-oil circulation would be adapted, as by this means the large coils and extremely large mass of iron necessary to form the magnetic circuit may be cooled without difficulty.

In small transformers suitable for pole suspension the advantages of the three-phase transformer are emphasized in appearance and reduction in weight.

In general, the two systems may be summed up as follows: where the plant is of small or medium size, the facilities for handling limited, and the floor space not an important feature, groups of one-phase transformers would, without doubt, be adopted. For large plants, however, having ample facilities for handling, and particularly where floor space is a question of importance, the three-phase type would be most suitable.

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RELATIVE ADVANTAGES OF ONE-PHASE AND THREE-PHASE TRANSFORMERS

BY JOHN S. PECK

In considering the relative advantages of three-phase and one-phase transformers it will be assumed at the outset that the three-phase transformer is to be compared with a group of three one-phase transformers whose aggregate output is the same as that of one three-phase transformer; for it will be admitted at once that a comparison between one one-phase transformer and one three-phase transformer of the same output would be all in favor of the one-phase transformer. On this assumption, the advantages of the three-phase transformer over the one-phase group are as follows:

1 Lower cost.
2 Higher efficiency.
3 Less floor space and less weight.
4 Simplification in outside wiring.
5 Reduced transportation charges and reduced cost of installation.

The disadvantages are:

1 Greater cost of spare units.
2 Greater derangement of service in the event of breakdown.
3 Greater cost of repair.
4 Reduced capacity obtainable in self-cooling units.
5 Greater difficulties in bringing out taps for a large number of voltages.

The various advantages and disadvantages enumerated above will be considered in sequence.

ADVANTAGES

1 *Lower Cost*—A three-phase transformer should always be cheaper to manufacture than three one-phase transformers of the same total output; for by combining one-phase units into a three-phase unit, there results a considerable saving in active material due to the magnetic phase relations. Also there is only one containing case, one set of end-frames, one cooling system, etc., to be provided for the three-phase unit.

The labor is also less, not only on account of there being less active material to handle one case, one set of end frames, etc., but because the unit as a whole is larger, and there is always less labor cost in manufacturing one large unit than there is in manufacturing several smaller units for the same total output.

2 *Higher Efficiency*—Since there is less active material in the three-phase transformer than in the one-phase group, the loss at the same densities will be less, and therefore the efficiencies higher, consequently the total radiating surface required may be less.

3 *Less Floor Space and Less Weight*—This follows from a consideration of 1 and 2.

4 *Simplification in Outside Wiring*—The star or delta connections of a three-phase transformer are simply and easily made inside the case, for as a rule only three high-tension and three low-tension leads are brought out; whereas with three one-phase transformers at least six high-tension and six low-tension leads are brought out and the transformers interconnected by suitable wiring.

5 *Reduced Transportation Charges and Reduced Cost of Installation*—The lighter weight and less bulk of the three-phase transformer will, in general, result in reduced transportation charges especially where shipment is made by water. This advantage is open to question, however, when there are long wagon hauls over mountain roads, with poor facilities for handling heavy machinery. In this case it may be cheaper to transport a greater weight and bulk in small units; but in general the transportation charges should be considerably in favor of the three-phase transformer.

It should also be noted that in many foreign countries duties are charged according to the weight of material, but whether duties are charged according to weight or price, the advantages are with the three phase transformer.

In general, it will be cheaper to install one large unit than three small ones. This is particularly true where the transformer must be dried out on site by heating or by vacuum process.

DISADVANTAGES

1 *Greater Cost of Spare Unit*—It is obvious that any three-phase unit having three times the capacity of a one-phase unit will cost considerably more. This may be of some importance where there is but one three-phase unit, but it will be found that in many cases the cost of two three-phase transformers with a total capacity of 200% will be but little more than that of four one-phase transformers having a total output of 133%. Where there are several similar three-phase units it will be found that the reduced first cost of adopting three-phase units will more than pay the difference in cost between the three-phase and the one-phase spare unit. In addition, there is the advantage that the three-phase spare unit will have three times the capacity of the one-phase spare unit.

It should be noted, however, that with a three-phase or one-phase core-type transformer, there is much less need of carrying a complete spare unit than with the shell-type one-phase or three-phase transformer. This is on account of the very simple coustruction of the core-type transformer, and the ease with which it may be repaired. The top-yoke is built up in one solid piece and bolted down with butt joints to the three vertical cores. Thus it is necessary in case of repairs to loosen only a few nuts, remove the top yoke, slide off the damaged coils, and replace them with new ones; bolt down the yoke and replace the transformer in position. Should the lamination be welded together, it might be necessary to do considerable filing; but in general there is less chance of burning the laminations than with the shell type of construction. With a supply of spare coils, any ordinary burn-out should be repaired in a very few hours. On the Continent it is quite customary to use core-type three-phase transformers with only coils as spares even for very important work; for it has been found in actual practice that repairs can be made in but little more time than, is required to replace one transformer by another.

With the present standard shell-type of construction, a much longer time is required for repairs on account of the fact that the laminations must be removed and replaced a few at a time. The repair of a three-phase shell-type transformer is so serious an undertaking that it would probably seldom be attempted on site but would be returned to the manufacturer.

2 *Greater Derangement of Service in the Event of Breakdown*—When three one-phase transformers are connected in delta on both high- and low-tension windings, one of the three may fail and be cut out, and the remaining ones will continue to carry about two-thirds the total load without overheating. With the star connnection on either winding, this cannot be done. A three-phase core-type transformer cannot be operated with a short-circuit on any phase. The three-phase shell-type transformer may be operated, however, with a short-circuit on one-phase provided both windings are in delta; but while this may be used as a temporary expedient for carrying partial loads, the whole transformer must be removed eventually for repairs.

In any event, whether core- or shell-type transformers are used, there will be probably a somewhat greater delay in substituting a three-phase spare unit than in substituting a one-phase spare unit.

3 *Greater Cost of Repair*—With three one-phase units it is probable that in the event of breakdown in one, it will be cut out before the others are damaged. With a three-phase unit, where the phases are so near together, there is the possibility that a breakdown in one-phase may damage one or both of the others. In such event, there are two or three phases instead of one to repair; but in any event the repair of a three-phase transformer will be in general more expensive than a one-phase transformer of the same type.

4 *Reduced Capacity Obtainable in Self-Cooling Three-Phase Units*—In some cases it is highly desirable to use only self-cooling transformers. 1500 kw. is approximately the maximum size of three-phase transformer that with present methods of construction, can be made self-cooling. A group of three one-phase self-cooling transformers can be built with an output of two or three times this amount. Thus, if an output greater than 1500 kw. is required, it will be necessary to use two three-phase transformers, a more expensive arrangement than three single-phase transformers. It is very seldom, however, that an out-put greater than 1500 kw. is required from a self-cooling transformer. When artificial cooling is permissible, the three-phase transformer may be built for any desired capacity.

5 *Greater Difficulties in Bringing out Taps for a Large Number of Voltages*—The increased difficulty in arranging the three-phase transformer for a large number of different voltages might in some cases prevent its use, but such cases will be of very rare occurrence, and need scarcely be considered.

To sum up, it may be said that the three-phase transformer has certain real and positive advantages over the one-phase type, while its disadvantages are chiefly those which result in the event of breakdown—an abnormal condition which occurs at rarer and rarer intervals as the art of transformer design and manufacture improves. It is the writer's belief that, as on the Continent, the three-phase transformer has already superseded the one-phase in most cases, so in America and Great Britain the use of the three-phase transformer will show a very rapid increase within the next few years.

It is also the writer's opinion that a three-phase core-type transformer having as good or better performance than the shell type can be built for less money. This, together with the fact that the core type can be repaired so readily, makes it more desirable than the shell type.

In the above discussion, the three-phase transformer has been compared with three one-phase transformers, but it is possible to use two one-phase transformers with the V or T connection for three-phase working; and by placing the two in the same case, a considerable saving in cost over three separate transformers may be effected. On account of the phase relations of the currents, however, the capacity of each transformer must be 15% greater than half the capacity of the three-phase transformer, with a corresponding increase in cost and losses.

There is another serious objection to this arrangement, for on account of the out-of-phase relation of voltage and current the voltage across the three phases will not remain in balance as the load comes on.

It is also open to very serious doubt whether this transformer can be built as cheaply as can the three-phase core type. The writer does not believe that this type will ever come into very general use.

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FORCED-OIL AND FORCED-WATER CIRCULATION FOR COOLING OIL-INSULATED TRANSFORMERS

BY C. C. CHESNEY

With the increased demand for large individual transformers, and for installations of large aggregate capacity, the relative merits of forced-oil and forced-water circulation for the cooling of oil-insulated transformers have been recently receiving the special attention of transformer designers.

The method of cooling transformers by means of forced-water circulation has been in use a number of years, and is too well known to require any more than a very general description. The essential feature is a cooling coil of pipe composed of a number of turns of iron, brass, or copper pipe placed in the oil in the upper part of the containing tank, and generally above and around the ends of the transformer windings. Through this coil is circulated the necessary cooling water, the heat being transferred from the winding and core to the pipe-coils by the natural circulation of the oil from the heated parts of the transformer to the cooler pipe-coil.

The more recent methods of cooling transformers by forced-oil circulation does away entirely with any internal cooling coils, but makes necessary external auxiliary cooling apparatus. The lower part of the windings of the transforme, is enclosed in a metal box containing suitable directing platesr and this box is connected to the oil inlet by a vertical pipe raised to the top of the tank and passing through the cover. The outlet pipe has its opening somewhat above the top of the windings, thereby insuring a safe oil level. Oil under a slight pressure is introduced through the inlet pipe, and in passing through the transformer the oil is brought into intimate contact with the various windings and laminations by means of ducts and directing plates. After leaving the transformer, the oil flows through an external cooling system containing a surface condenser and strainer, and an oil pump, the latter providing the pressure needed to keep the oil moving at a proper rate through the entire system. An additional pump is provided to circulate water through the condenser. Sufficient water is usually circulated through the condenser to give a 10° cent. rise to the water temperature, and the rate of oil-flow is usually adjusted to approximately twice that of the water. The organization of the entire cooling system is shown in Fig. 1.

To offset the additional cost which this auxiliary cooling apparatus represents, there is a less first cost of the transformer proper, due to the markedly more efficient cooling which the positive circulation of the oil insures, and to the prevention of any local heating, in pockets, etc. The density in both copper and iron can be increased for the same temperature rise, which means less material used in the design of the transformer. In addition, since there is no cooling coil, the tank can be reduced in height, and less oil will be needed to fill it.

The total saving in the transformer proper will vary from 15 to 25%, depending upon the size of the transformer. The reduced height of the transformer is, however, particularly welcomed on the score of shipment. With forced-water circulation the designer is handicapped, in the larger sizes, by being limited to a height of approximately 11 feet; this being the maximum height that can be safely shipped on any of the American railroads. By the use of forced-oil apparatus, however, the capacity of the transformer which can be shipped completely assembled is materially increased. On the other hand, as against the gain in head-room the total floor space required will be greater, on account of the additional floor space required for the auxiliary cooling apparatus.

If a comparison of the total cost of the transformers installed is taken, the balance in favor of the forced-oil system appears for the large installations of 4000 to 5000 kw. when composed of individual transformer units of not less than 1200 to 1500 kw. While forced-oil circulation is undoubtedly out of the qestion for smaller plants and smaller units, it merits for the large power plants the most careful consideration of any engineer.

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ENCLOSED STATION WIRING

BY F. O. BLACKWELL

In the design of a power station, the wiring is often given but scant consideration, and is fitted into such spaces as may be left over and not available for other purposes. In reality, a safe system of station wiring is as important as reliable machinery and should be given thorough consideration in making the plans of the building. Power houses have frequently been shut down by animals getting across the conductors and by

Fig. 1

materials accidentally coming in contact with them. Men working about a building may be killed or injured seriously by exposed electrical connections. Once started, it is impossible to say how much damage an arc will do with open wiring. In every case the service is likely to be interrupted.

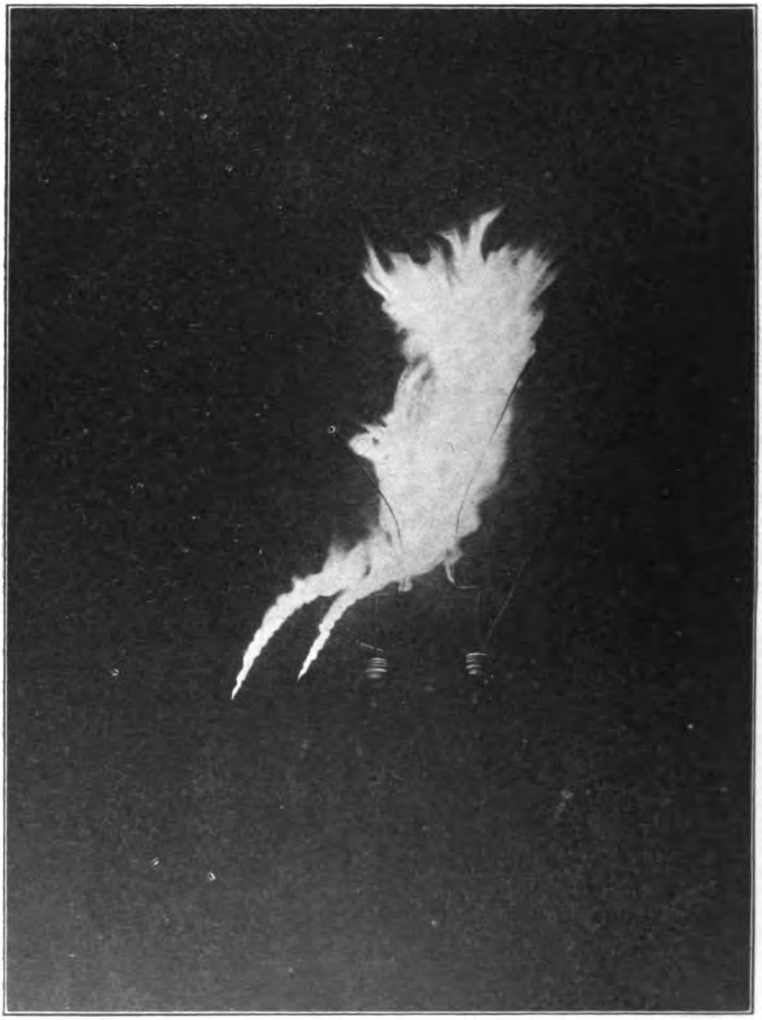

FIG. 2

In the power house of a few years ago, when the amount of power was relatively small, a short-circuit was not a serious matter; but to-day, with 50,000 or 100,000 h.p. concentrated in one plant, a much higher standard of station wiring is called for.

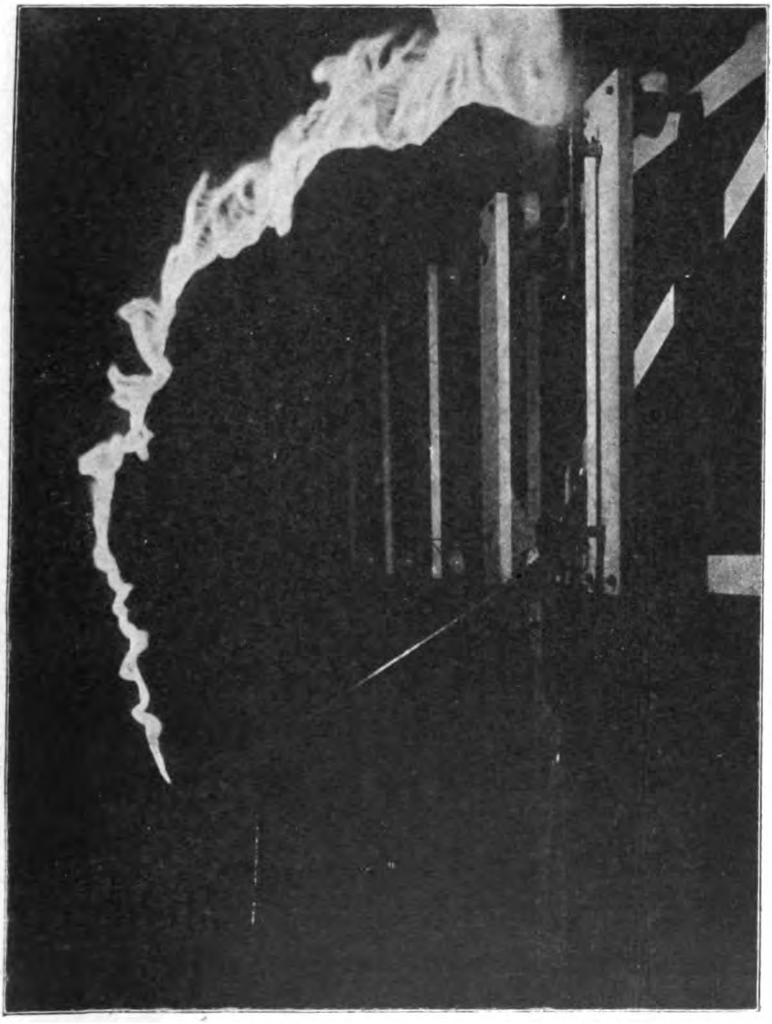

FIG. 3

With a large amount of power the destructive ability of an arc is enormously increased, and the use of high potentials has made it possible for arcs, once started, to jump almost any distance if not confined.

The direct loss of income is large, but this is nothing to the indirect loss due to the depreciation in the selling value of the power output, caused by loss of public confidence in the reliability of the service.

The attached photographs will give some idea of high-potential arcs, although none of them has any great amount of power back of it, or is of as high potential as is now generally used.

Figs. 1 and 2 show arcs on a 40,000-volt 2,000-kw. system which, in a light breeze, jumped some 40 ft.

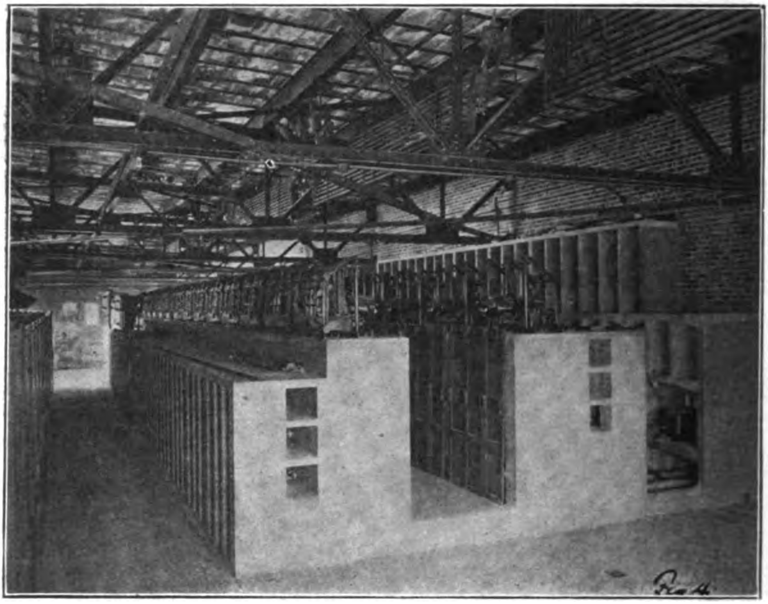

Fig. 4

Fig. 3 illustrates a 30,000-volt air-switch opening with no load except the charging current of the line.

The metal vapor from an arc, even after the current has been interrupted, will often short-circuit conductors at a distance from the point where the arc started. Wires of high-potential circuits which are as far apart as it is possible to have them inside of a building, may be affected by arcs between low-potential conductors beneath them.

Lightning striking in the neighborhood of a transmission line has been known to cause a short-circuit after the discharge was over, due to the path of hot gas floating across the wires.

In order to prevent the occurrence of short-circuits, and to localize the damage should an arc start from any cause, the following elementary principles should be observed:

1. The system of connection should be as simple as will give the necessary control over the station.

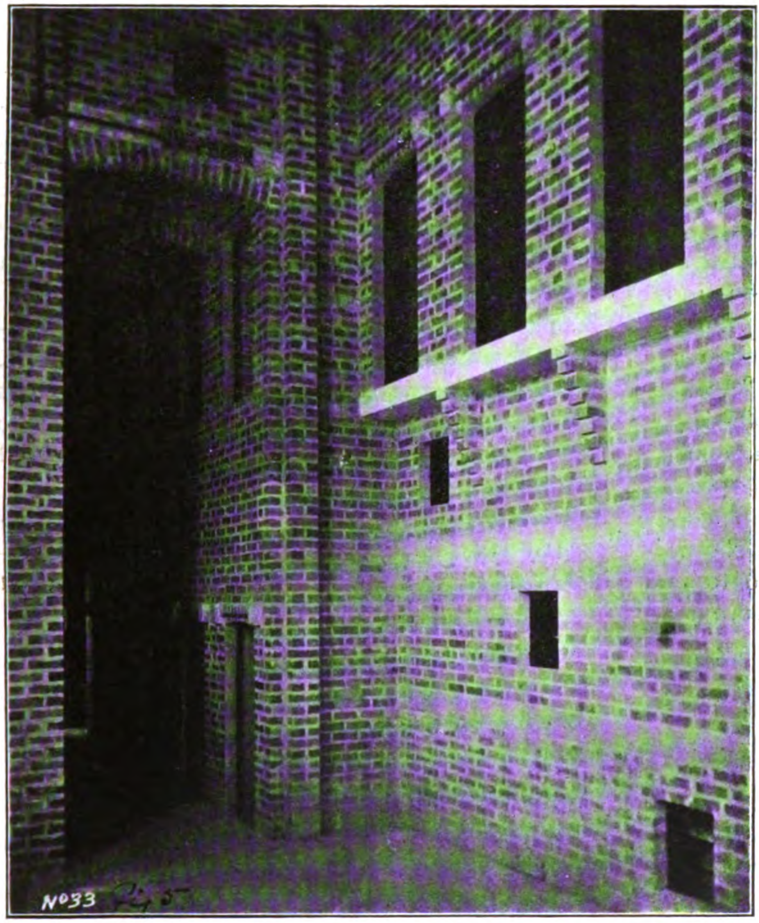

FIG. 5

2. The conductors should follow the shortest and most direct line from generator to transmission line.

3. Each conductor should be surrounded and separated from every other by a continuous fire-proof barrier.

4. The circuits should be as far apart as possible.

Enclosed wiring has already become the accepted practice in important low-tension plants of from 2,000 to 15,000 volts, but is not used as generally for higher potential where the writer believes it is much more important.

Low-potential insulated cables, drawn through ducts or enclosed by split-tile or pipe coverings, are safe provided care is used to cover the cable joints at the manholes, as a cable-joint is a frequent source of trouble.

A single-cable tunnel, or duct system with common manholes through which all the cables in a plant run the length of a building is often employed, in which, if anything goes wrong with one cable, the entire power house is disabled. Accidents of this kind might be avoided by keeping the cables from each unit in a conduit at a distance from other circuits, and laying out the wiring so that each generator can be operated as if it were in a separate power station.

Where bare conductors are used on account of many connections, or where the potential is too high for insulated cables, the wires should be enclosed by substantial walls or barriers of brick, concrete, tile, or stone with only such openings as are necessary to get at insulators or connections. Covers should be provided for all openings.

A good example of enclosed wiring for 13,000 and 60,000 volts is shown in Figs. 4 and 5. These photographs are from the Toronto and Niagara Power Company's transformer house at Toronto.

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POTENTIAL STRESSES AS AFFECTED BY OVERHEAD GROUNDED CONDUCTORS.

BY R. P. JACKSON.

This paper is a theoretical investigation of the potential gradients and the equipotential surfaces about grounded conductors suspended in the air, and also about metallic towers for supporting transmission lines. It is obvious that equipotential surfaces surround all conducting material subject to static strain, but the position of these surfaces and the gradient of change at different points are usually difficult to determine.

An example is furnished in the overhead grounded wire sometimes used as a protection for a transmission line against lightning. Such a wire placed above a transmission line serves two purposes: first, it interposes a grounded conductor between the sky and the transmission line, and tends to relieve the line from direct strokes (the effectiveness of the grounded wire for this purpose will probably depend largely on its size and the frequency with which it is grounded); secondly, a much more frequent condition, however, is the stress due to induced potential between the transmission wire and ground. If we make an assumption which seems reasonable that there is a potential stress between a cloud and the ground, and that the distribution of this stress is nearly uniform, at least in the vicinity of the earth's surface; that is, that the potential due to the cloud is proportional to the height above the ground, and the potential gradient is, therefore, approximately a straight line near the ground, it is possible to determine in what way this gradient will be altered by the presence of a grounded conductor some distance above the earth.

The potential at a point near an indefinitely long cylinder remote from other conductors is proportional to the logarithm of its distance from the center of the cylinder. If the potential at the point also tends to be proportional to its distance above the ground, its resultant potential will be the algebraic sum of the two. Obviously, the surface of the ground is itself an equipotential surface; for if it were not, current would flow from the points of high to those of low potential, and it would immediately become an equipotential surface. This fact, that the earth is conducting, cannot be represented mathematically, so it is necessary to assume an image of a charged object the same distance below the earth's surface as the real object is above, and that its charge is always of opposite sign. The surface of the earth then becomes of uniform potential without assuming that it is conducting. The equation for potential of a point near a grounded wire then becomes

$$C\,H - K \log \frac{R}{r} = P \qquad (1)$$

where H is the distance of the point above the ground, C and K are constants, and R and r are distances of the point from the image and the wire respectively. P is then the potential of the point taken. By taking the point on the surface of the grounded conductor, H, R, r, and P become known. The constant, C, is determined by the assumed gradient, so the constant K may then be determined, and if logarithms to the base 10 are used, will include the proper modulus.

In Fig. 1 a 0.5-in. wire 50 ft. above the ground has been assumed. The gradient is taken at two per foot, so that if the wire were not there the potential at the point where it has been assumed would be 100. This is convenient so that values deduced may also be used as per cent. ratios. The equation becomes approximately

$$2\,H - 30 \log \frac{R}{r} = P \ (2).$$

All the curves of Fig. 1 are calculated from this equation.

It may be seen that at no point directly beneath the grounded conductor is the potential greater than 52. Curve G becomes the gradient instead of N. The meaning of this is that a transmission wire placed, say 5 ft. below the grounded wire, would, when there was a charged cloud overhead, have a potential of about 55% of that which would exist if there were no grounded wire tending to cause a charge to leak from ground to the transmission line. Again, after the cloud has discharged there would be only 55% as great a potential on the wire, and consequently only 55% as great a charge to escape suddenly to ground. In other words, the curves do not indicate that complete protection is obtainable from a single wire, but that under certain conditions a material reduction of static stress will occur. The amount of this reduction is dependent on the relative positions of the transmission line and the grounded conductor.

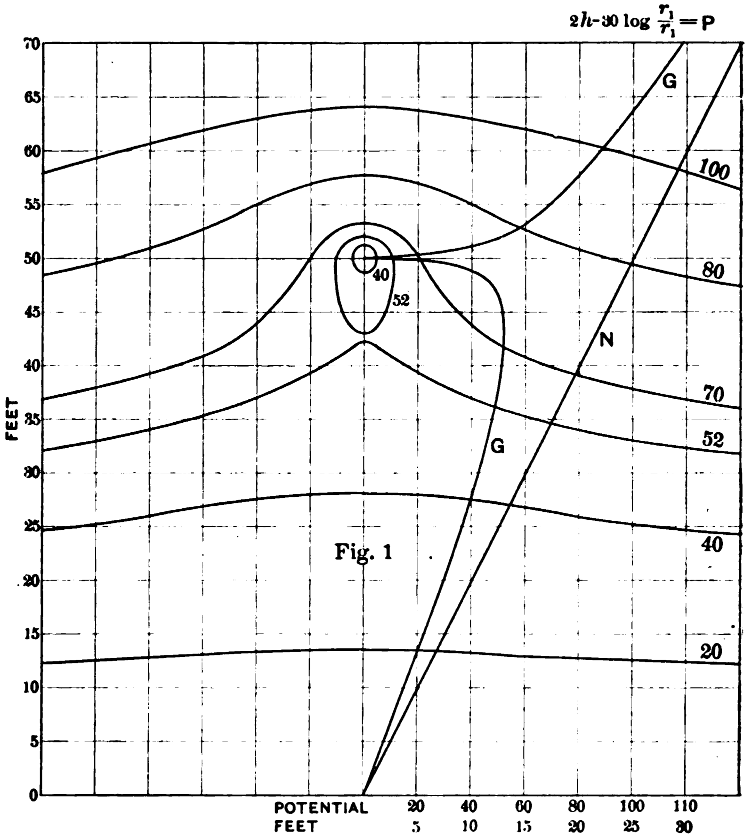


Fig. 1

The equation given for a single conductor may easily be elaborated to cover any number of conductors of various sizes, distances apart, and height above ground. By taking the point for which the potential is determined by equation (2) on the different wires in succession, as many equations will be obtained as there are constants, so all may be determined.

The equation for two wires, 10 ft. apart, 50 ft. high, and 0.5 in. in diameter, becomes

$$2\,H-23\ \log\frac{RR}{rr}=P.$$

Fig. 2 shows the corresponding curves. It will, of course, be true that the protected area is considerably larger. Fig. 3 shows the assumed gradient, a straight line reaching a value of 100 at a height of 50 ft., and also shows the gradients on a medial, plane for one 0.5-in. wire, 50 ft. high, two 0.5-in. wires, 10 ft. apart, and 50 ft. high, and the same plus another wire between them and 5 ft. higher. Curve 1 being for one wire, Curve 2 for two wires, and Curve 3 for the three wires, respectively. If a number of wires were arranged either in a horizontal plane or cylindrically with the concave side towards the earth, there would be a large

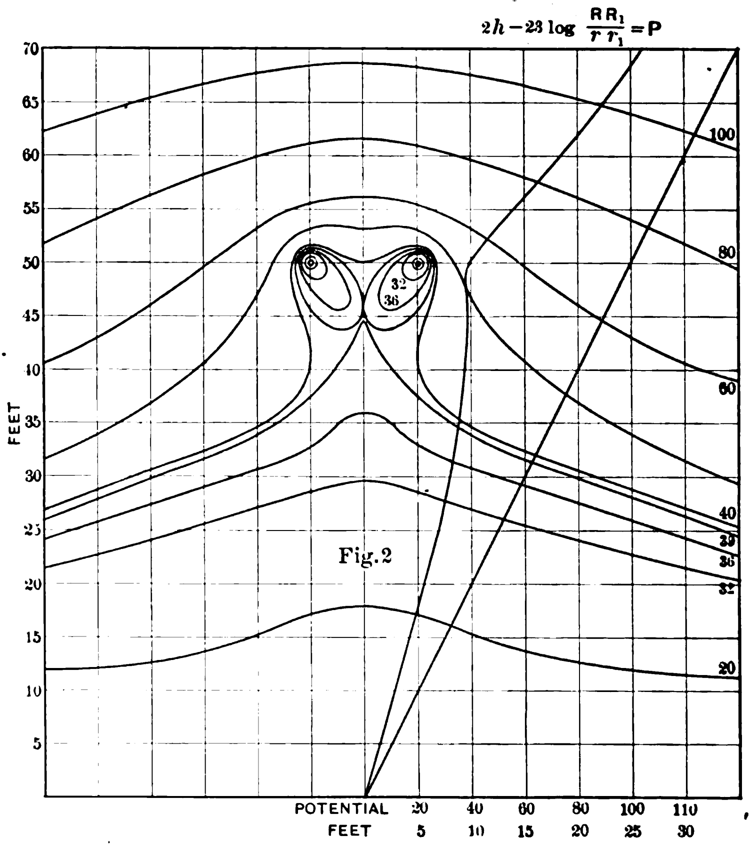


Fig. 2

area of low potential covered which would probably be a comparatively safe location for a transmission line.

The above deductions are based on the assumption that the transmission wires are completely insulated, both from the ground and from the other parts of the circuit not affected by the cloud potential. Insulated uncharged conductors of small dimensions in the direction of the static stress have no appreciable effect on the static field about them. The above is a condition, however, that would be practically impossible on a real transmission line, since it is reasonably certain that either the insulators will leak sufficiently soon to supply the small charge necessary to relieve the potential stress, or such charges will be supplied through a grounded neutral, if there be one, or by the capacity of the remainder of the circuit not affected by the cloud potential. In any case the gradually developed stress due to the cloud will be relieved by charges appearing on the transmission wires, but when the cloud suddenly discharges by a lightning flash the charges on the line wires escape suddenly either lengthwise on the wires and into power stations, or over insulators at the points where the stress is greatest.

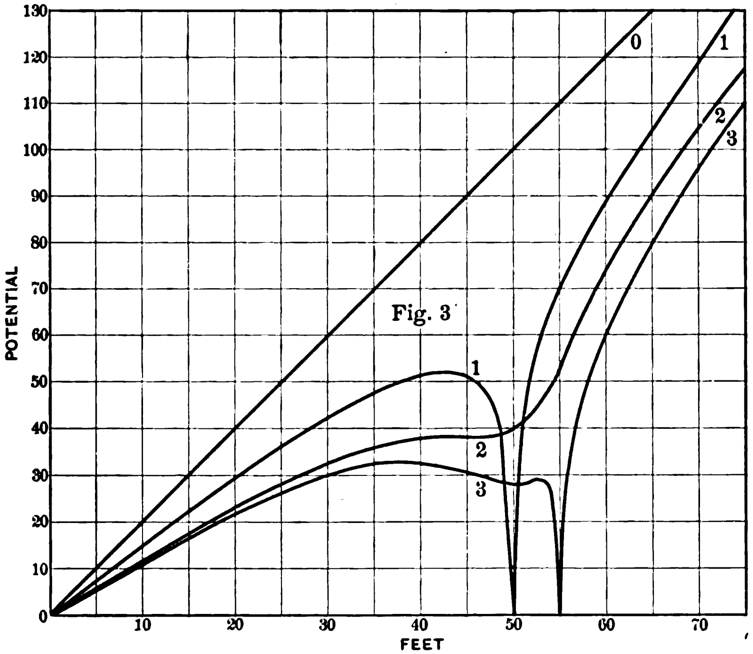
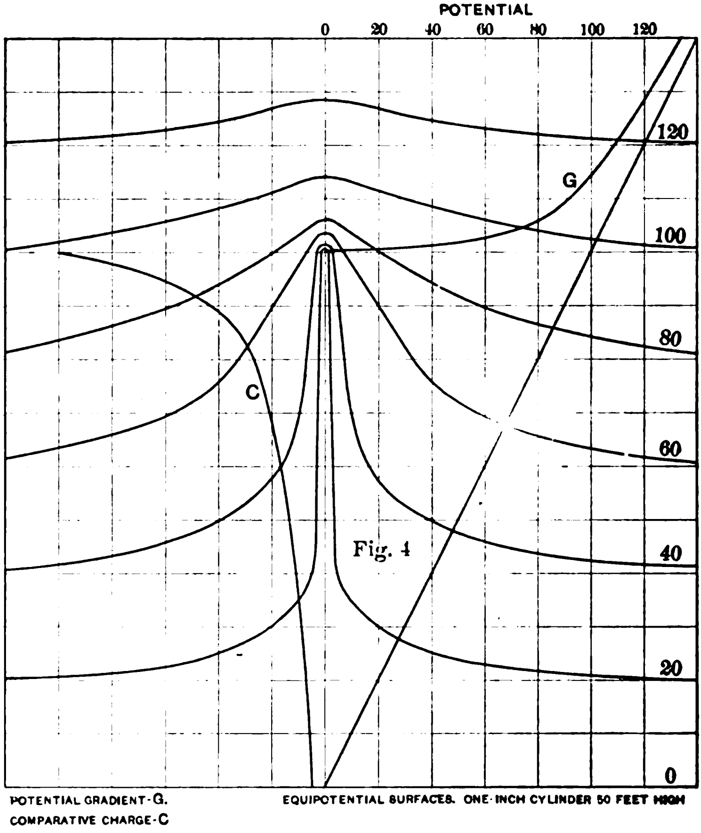


Fig. 3

By the fundamental principle of the conservation of energy, the potential stress which will cause a charge to appear on a wire will be reproduced in the opposite direction by that charge, if the original stress be removed. This also holds good when a grounded wire is placed above a transmission line, so although curves of Figs. 1, 2, and 3 are calculated on the basis of perfectly insulated line wires, they hold equally good for an actual transmission line where charges could readily find their way to the parts of the line under stress by the paths previously mentioned. This can be proved mathematically, independently of the principle of conservation of energy referred to above.



If the line were so insulated that only a partial charge could leak to the transmission wires, the primary stresses would be reduced somewhat, but the grounded wire would still have the same beneficial effect.

It is obvious that to get the full benefit of the grounded conductors, they should be thoroughly and frequently connected to the ground, as their effectiveness consists in releasing their own charge at the moment of a lightning flash, and immediately receiving another of opposite sign from the ground. This latter charge is then of opposite sign to that which still remains on the transmission wires, and serves to reduce the potential of these wires.

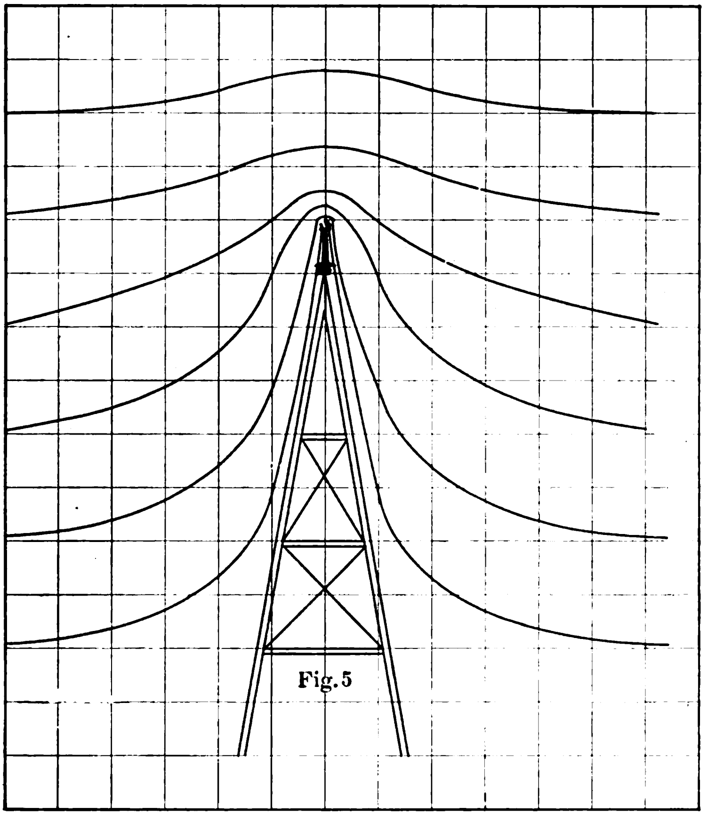


Fig. 5

It will be noted in Figs. 1 and 2, that the lines representing the equipotential surfaces are closely crowded together on the upper side of the grounded wire. This characteristic is much more marked in the case of a tower or spire projecting toward the sky. The potential of a point near such an object is much more difficult to calculate, so in Fig. 4, a 1-in. conducting vertical cylinder 50 ft. high was assumed, and the equipotential surfaces calculated. Curve *C* shows approximately the proportional charge at different points along the cylinder. Curve *G* shows the potential gradient from the top of the cylinder. It is seen that the charge density becomes relatively very great at the top of the pole or cylinder, and that the change of potential is very rapid for the first two or three feet above the top of the cylinder. This is a condition tending to produce leakage into the atmosphere, or corona effect, such as the St. Elmo's light seen at times on mastheads of vessels.

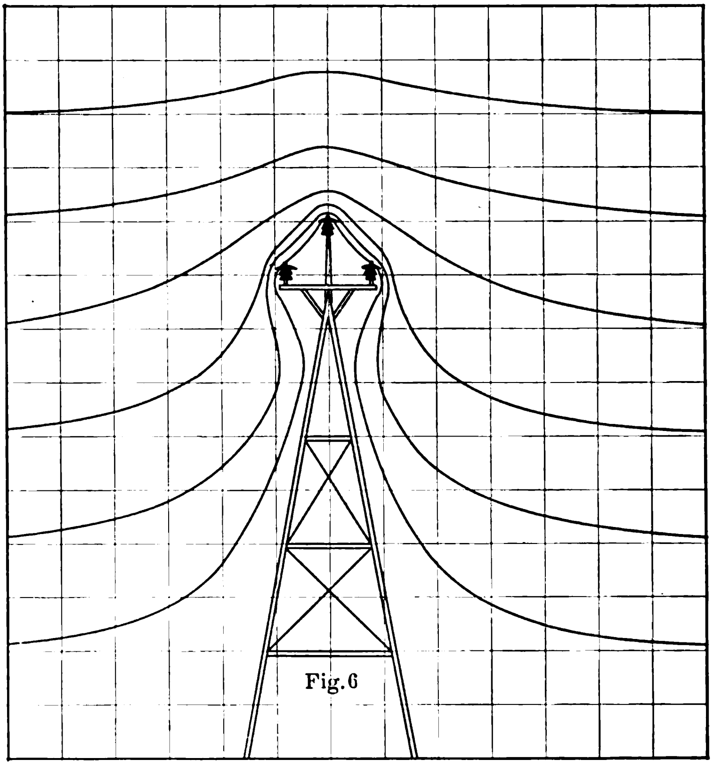


Fig. 6

Apparently, if an insulator were placed on the top of this cylinder, and a high-potential conductor were carried by this insulator, there might develop a conducting state in the atmosphere about this insulator that would cause it to flash over. especially if there were any sudden rise of potential on the conductor carried by the insulator. Fig. 5 shows one view of a metal tower under this condition, and Fig. 6 another view.

Fig. 7 shows the natural suggestion for relief. If the tower structure were carried higher, and the insulators and transmission wires suspended downwards, the desired result would be obtained without the additional shielding device shown in Fig. 7.

All the discussion given in this paper is, of course, pure theory, and if there were never any insulators broken, or other trouble from lightning strains, it would have no practical value. Insulators are broken, however, especially those carried on metallic towers. So, while the information given in the curves does not indicate to any degree how much trouble can be eliminated by the devices discussed, there seem to be suggestions as to the most effective arrangement of such devices. If line insulators are subjected to frequent stresses of a value five times that which they will stand, a reduction of 50% would

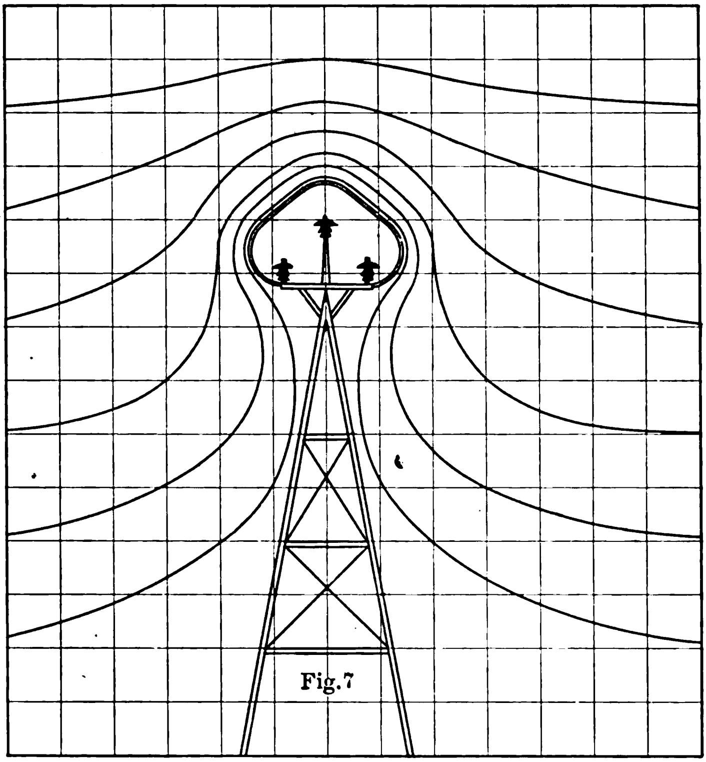


Fig. 7

not avail much. If, however, the average of normal stresses to which they are subject are only 150% of the breakdown value, a reduction of one-half in these stresses may eliminate a very large amount of trouble.

The general conclusions are as follows:

1. Properly placed and grounded conductors above a transmission line ought materially to reduce the electrostatic stresses to which the insulators will be subjected.
2. An insulator interposed between a high metallic structure and the sky, without a grounded conductor above the insulator to act as a shield, is exceptionally liable to breakdown.

A paper presented at the 218th Meeting of the American Institute of Electrical Engineers, New. York., April 26, 1907.

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THE TELEPHONE WIRE PLANT

BY SERGIUS P. GRACE

Telephone engineering has been looked upon by many engineers as principally a switchboard problem. The switchboard problem was undoubtedly deserving of the great amount of attention given to it by telephone engineers, and the results are everywhere evident to-day in the perfect working mechanisms of the modern, central battery switchboard. An analysis of the construction costs of the telephone plant will, however, show that from two-thirds to three-fourths of the total expenditure is required for the outside plant; that is, for conduits, poles, cables, and wire. Because of the very large proportional expenditures for the outside plant, it becomes evident that the systems of line distribution should be most carefully studied in order that the best service may be given at the lowest cost.

In considering a telephone plant for a community, the first thing to be done is to decide upon a proper development plan for the growth of the business for a reasonable number of years. In view of the rapid advances in the telephone art and the possibilities of the introduction of new systems of transportation and communication, it would seem that fifteen to twenty years is as far ahead as we are justified in planning telephone development. If the plant is to care for service offered during this period, it must be originally so laid out and designed that the additional subscribers can be taken on without the redesign and reconstruction of the plant. From time to time the development plan can be revised so as always to keep it from fifteen to twenty years ahead of the plant. In laying out a telephone development plan for a city, there are many things to be considered. The growth in population for the last ten years must be carefully considered; from all possible sources of information a prediction should be made of the population for the next ten to twenty years. It next becomes necessary to determine upon the percentage of development which may reasonably be expected; that is, the ratio of telephones in use to the population. This will vary considerably with the prosperity of the community and whether there are large manufacturing districts employing low grades of labor. It seems certain that this development in the ultimate will lie between 15 and 30 per cent. of the total population. A careful estimate must also be made of the ratio of line tos stations. Thus if a very high party-line development is expected, the ratio of lines to stations will be low. To-day the telephone line really means more to us from the wire plant standpoint than the number of telephones. Formerly we used to consider the number of telephones as affecting the wire plant; now it is the number of lines. Because of the introduction of private branch exchanges two or three trunk lines may care for fifteen or twenty telephones, or there may be a number of telephones on one line, so it is the line in which we are interested.

After having looked over the city in a general way and obtained the best available data regarding the industries and the growth of the population in various parts of the city, the next thing to do is to resort to a detailed count of all the buildings, and block by block make an estimate of the number of telephones expected at the end of various periods during the next twenty years. In addition to the count of the present buildings, an estimate should be made of the probable ultimate number of the various classes of structures in each built up block of the exchange area. In providing for the number of lines to be installed at once, which at the same time should provide for two or three years' growth, the present number of lines in each block should be determined and to this number about one-third more lines should be added. This will vary in different cities and must be the subject of a special study in each case.

After having made a study of each block in the exchange area and determined the probable number of lines and stations at the end of each five year period during the next twenty years, the entire number of lines and stations as shown by the block map should be summed up and carefully compared with the ultimate figures deduced from the general development plan which is based upon the character of the city and the probable growth in population. If the estimates arrived at by the general development scheme and the detailed block scheme do not compare favorably, both estimates should be gone into again most carefully to determine the possible

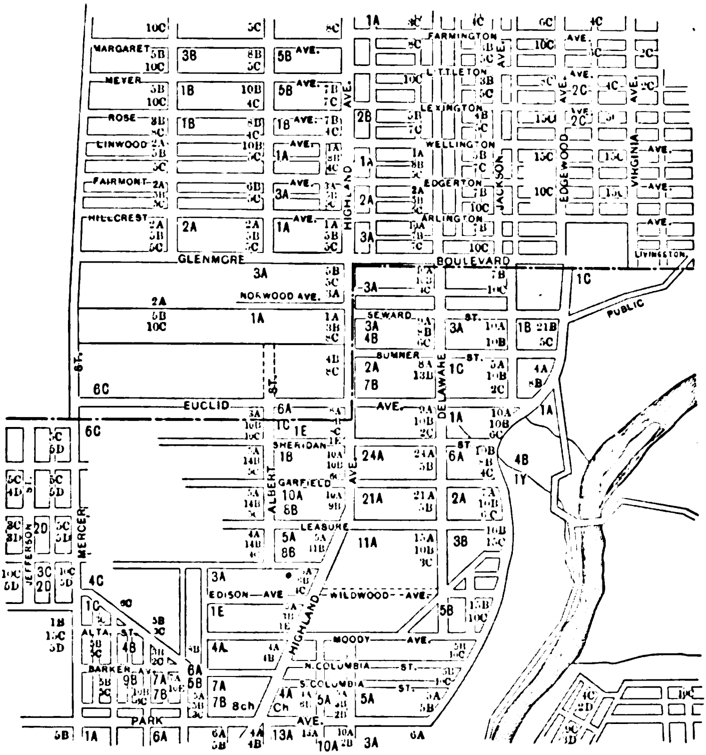


FIG. 1—Development plan Present ultimate number and classes of houses in each block

errors. In Fig. 1 is shown a section of a city of about 40,000 inhabitants. On this map are marked the numbers of the various classes of houses. At the left of the block in circles are shown present number and at right are shown ultimate number of houses. In Fig. 2 are shown the number in five years and ultimate number of lines in each block.

When the number of telephones in each block for the twenty-year study has been decided upon, it remains to determine the most economical grouping of these telephone lines into exchanges. In small cities where the number of telephone lines in the ultimate will not exceed 8,000 to 10,000, it is reasonably certain to assume that one exchange will prove the most economical. If the district is very much scattered or very much elongated this is not true, and the proper number of exchanges

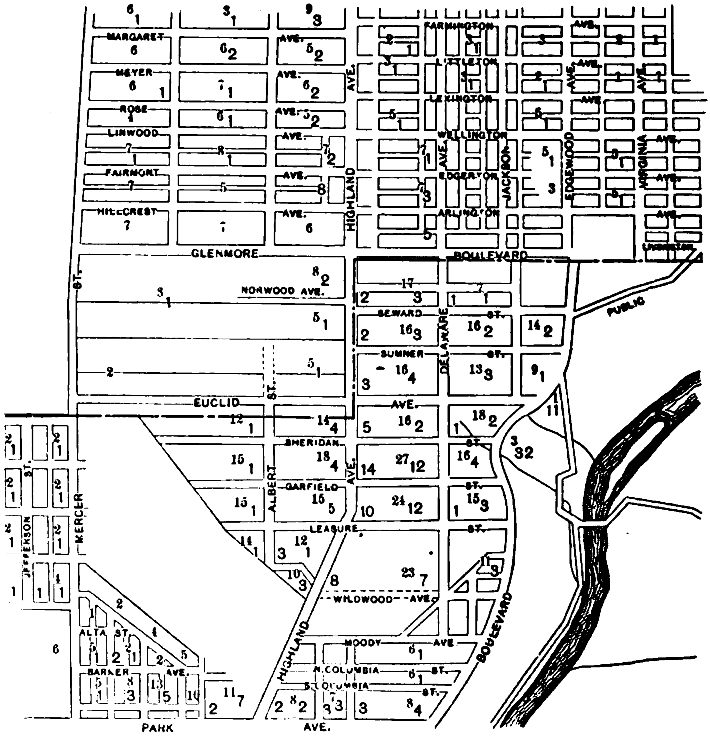


FIG. 2—Development plan Number of lines in five years and ultimate number of lines in each block.

should be determined in a manner to be described later. If one exchange is decided upon, a location for this exchange must be determined which will make the subscribers' line wire mileage a minimum. The determination of this center with extreme precision is a problem for the calculus. The most simple case is when the streets are all rectangular, in which case the mathematical centre of distribution is found by drawing lines at right angles through the exchange area, so that the number of telephones in the ultimate on each side of the lines is the same. If the present centre is a considerable distance from the ultimate centre, a mean centre between the two should be decided upon.

When the centre is determined, a complete conduit system should be laid out, touching at least one side of every block in the exchange area. It will never be necessary to construct all this conduit at once, and perhaps even in the ultimate much of it will not be installed, but if a definite plan is prepared the conduit extensions from time to time will be of correct dimensions and in the right direction. This conduit must, of course, feed to the exchange center by the most direct routes possible, and the lines should be concentrated in the smallest number of subways which will not affect the efficiency of the distributing system. Since it is known from the development plans the number of lines in each block at the present and the ultimate periods, a skeleton feeder plan carrying these pairs back to the exchange centre can readily be prepared, and from this it is easy to determine the number of ducts and sizes of manholes in the various parts of the subway. In Fig. 3 is shown a typical conduit plan. In general, the terminal cables feeding into the block should be of the ultimate size, while the feeder cables back to the exchange center should be so proportioned as to care for the growth in business for from two to five years. Fig. 4 shows a cable plan for a five-year growth. In the districts where conduit is not constructed, pole lines may be used for distribution and feeder purposes.

In the case of a large city where it is evident that a number of offices will be required to furnish the service, it is a very complex and complicated problem to determine how many exchange districts there should be. The cheapest number of districts will vary as follows:

1. With the grade of talking transmission.
2. With the subscribers mileage—varies directly as the number of offices.
3. With the *A* and *B* position equipment—varies directly as the number of switchboards.
4. With the multiple jacks—varies inversely as the number of switchboards.
5. With the rent—varies directly as the number of offices.
6. With the office constant—varies directly as the number

of offices. This office constant takes care of the equipment which is common to all offices, such as the charging dynamos, storage-batteries and power boards.

7. With the central-office labor—varies directly as the number of offices.

8. With the trunk mileage—varies directly as the number of offices; also on number of calls per line and per cent. of trunking.

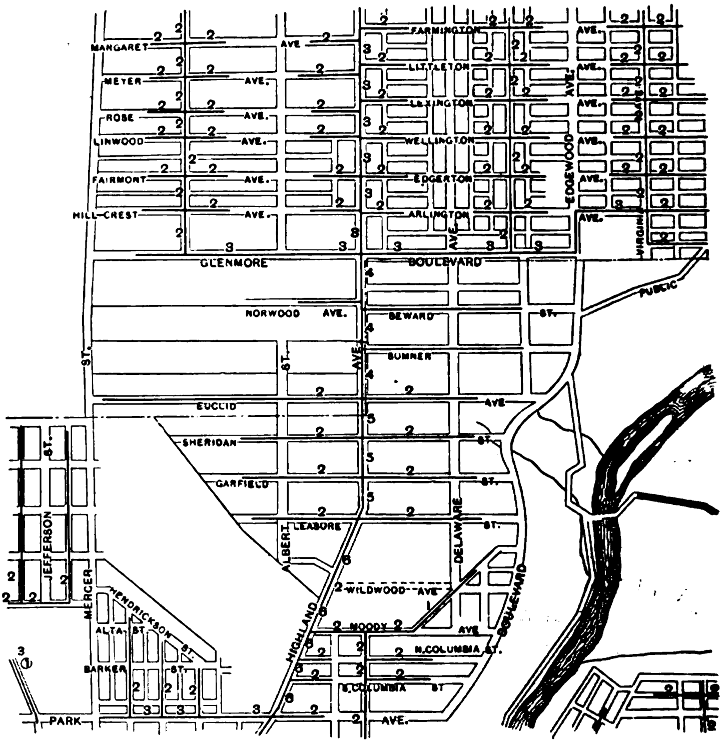


FIG. 3—Development plan. Typical underground conduit layout

Good telephone service is fundamentally based upon good talking efficiency. The means for transmitting the talk is what the telephone company really furnishes to the subscriber. In very large city districts, because of the distances between the central offices, the cost per message is materially increased on account of the high-grade trunk plant required to give the subscribers good transmission. The central battery system of subscribers lines has proved very efficient and economical from service and maintenance standpoints. There is, however, a considerable loss introduced into each line by the ohmic resistance which operates to cut down the flow of current through the transmitter. In addition, then, to the attenuation loss present in all cases we have added to this in the transmitting loop a loss due to the reduction of the current through the transmitter.

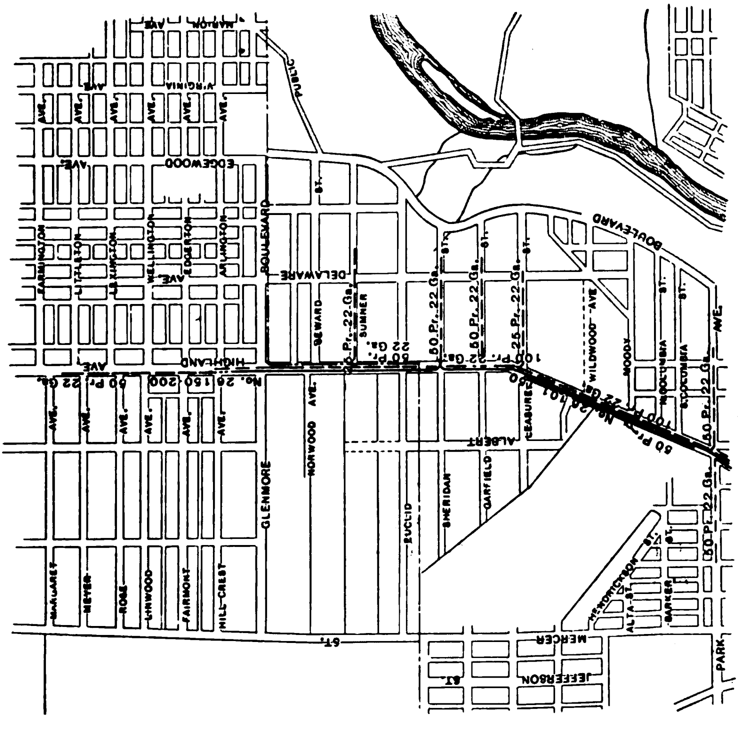


FIG. 4—Development plan. Cable plan for five years' growth

In designing the subscribers lines, 22-gauge cable should be used as much as possible. In the case of a large city with a number of central offices there is a limiting resistance for the subscribers' lines which can not be exceeded without making the trunking plant very expensive. This limiting resistance of the subscribers' line will vary in different cities because of the varying distances between central offices which affects the trunk line mileage. In general the subscribers' and trunk line plant must be so designed that, while there will always be good talking transmission between the subscribers, the annual charges on both the subscribers' and trunk line plant will be a minimum.

To lay out a city in the correct number of districts all the items above mentioned must be given careful consideration. From past experience it is generally possible to predict approximately the number of districts which will be found most economical. A number of districts above and below this value should be decided upon, and the costs and annual charges for each of these three groupings should be carefully calculated. The first cost and annual charges of all the variables given on preceding pages must be known in order to make these comparisons. Our past experience indicates that the following is about the best theoretical number of districts for cities of various sizes.

	Offices.
For an ultimate of 10,000 lines or less	1
For 10,000 to 15,000 lines	2–4
For 15,000 to 25,000 lines	5–8
For 25,000 to 35,000 lines	6–10
For 35,000 to 50,000 lines	8–12
For 50,000 to 100,000 lines	10–16

After the number of offices has been decided upon, and the conduit study following the general development plan is made, it yet remains to construct the outside plant so as efficiently and economically to connect the subscribers by means of the wire plant to the central offices. Conduits should be built in the congested districts and along what may be considered as main feeder routes. In general it is economical to construct at once a conduit if 400 to 800 pairs of wires are expected within five years. In the vicinity of the underground conduit system every effort should be made to connect the subscribers without resorting to aerial construction. Where the buildings are large and permanent and an average of ten telephones per building may be expected, the best method of construction is a cable directly into each building from the nearest manhole in the main conduit system. In the case of large office buildings one or more building cables should be run vertically in the wire or pipe shafts and terminal boxes provided at each floor, to which can be connected the individual wires for each telephone. The scheme

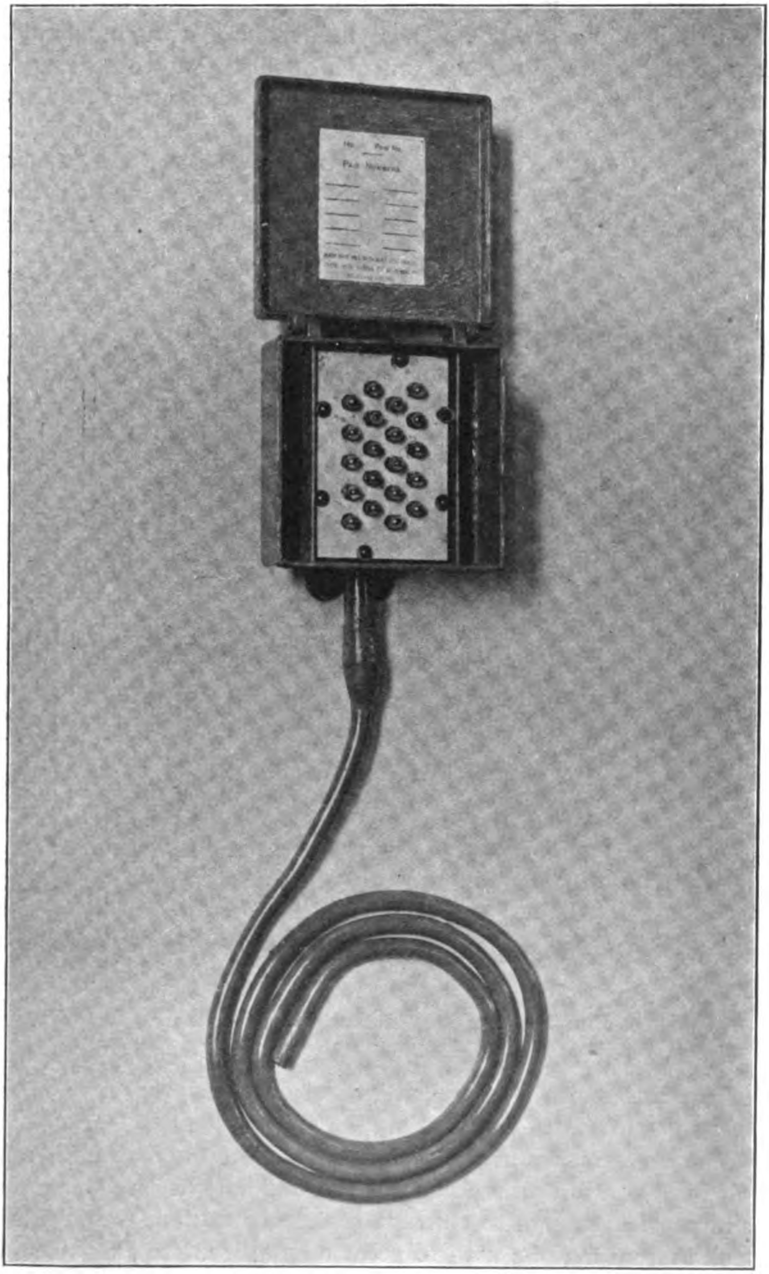


Fig. 5—Standard cable terminal

for distributing these individual wires most to be preferred is the hall molding scheme. These hall molding troughs should connect to the terminal box on each floor so that the wires to each telephone may be run from time to time as needed. This system is cheaper to install and easier to maintain than the conduit system following electric light practice. In many cities there are large area ways under the sidewalks, and a cable run through these area ways from one building to another and provided with a tapping terminal on each property makes a very good form of distribution.

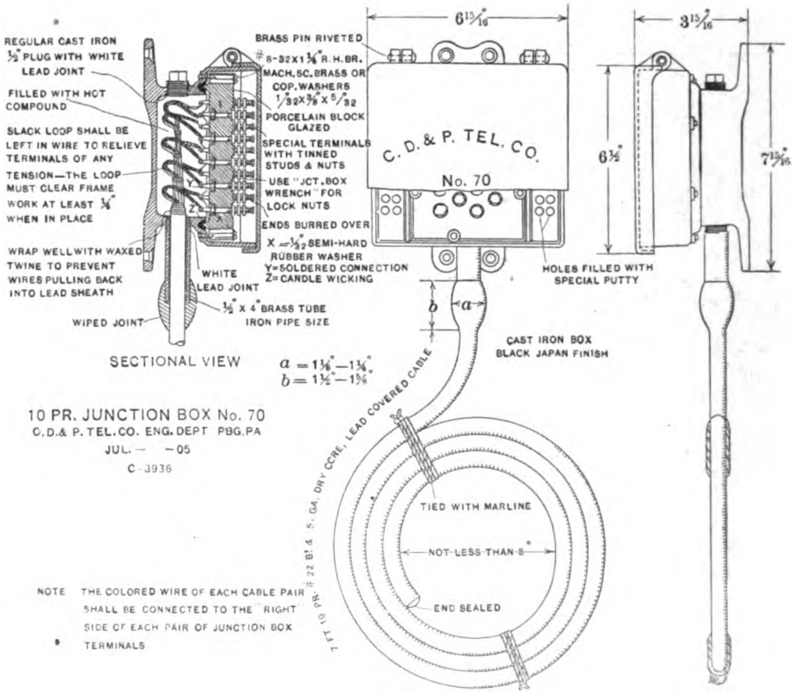
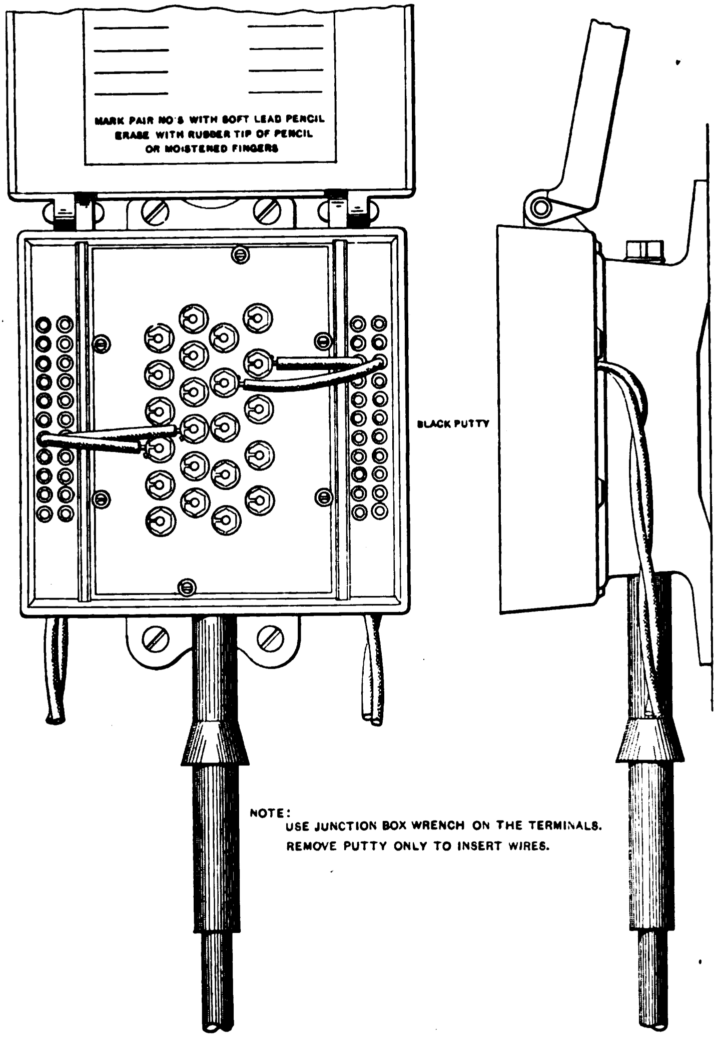

REGULAR CAST IRON ½" PLUG WITH WHITE LEAD JOINT
FILLED WITH HOT COMPOUND
SLACK LOOP SHALL BE LEFT IN WIRE TO RELIEVE TERMINALS OF ANY TENSION—THE LOOP MUST CLEAR FRAME WORK AT LEAST ¼" WHEN IN PLACE
WRAP WELL WITH WAXED TWINE TO PREVENT WIRES PULLING BACK INTO LEAD SHEATH
WIPED JOINT
WHITE LEAD JOINT
BRASS PIN RIVETED
#8-32×1¼" R.H.BR. MACH.SC.BRASS OR COP.WASHERS 1/32×3/8"×5/32
PORCELAIN BLOCK GLAZED
SPECIAL TERMINALS WITH TINNED STUDS & NUTS
USE "JCT.BOX WRENCH" FOR LOCK NUTS
ENDS BURRED OVER
X = 1/32" SEMI-HARD RUBBER WASHER
Y = SOLDERED CONNECTION
Z = CANDLE WICKING
½" X 4" BRASS TUBE IRON PIPE SIZE
Y
Z
X
SECTIONAL VIEW
a = 1⅛"—1¼"
b = 1½"—1⅝"
10 PR. JUNCTION BOX No. 70
C.D.& P. TEL.CO. ENG.DEPT PBG.PA
JUL. — —05
C 3936
NOTE THE COLORED WIRE OF EACH CABLE PAIR SHALL BE CONNECTED TO THE "RIGHT" SIDE OF EACH PAIR OF JUNCTION BOX TERMINALS
6 13/16"
3 13/16"
C. D. & P. TEL. CO.
No. 70
6¼"
7 13/16"
HOLES FILLED WITH SPECIAL PUTTY
CAST IRON BOX BLACK JAPAN FINISH
b
a
1 FT 10 PR. #22 B! & S. GA. DRY CORE, LEAD COVERED CABLE
TIED WITH MARLINE
NOT LESS THAN 8"
END SEALED

FIG. 6—Details of standard cable terminal

Where the blocks in the vicinity of underground conduit are well built up, but where none of the buildings is large enough or important enough to warrant direct connection the interior block system may be used to great advantage. In this system one or more underground laterals from the main subway system are run into the interior of the block and terminated on the

METHOD OF WIRING 14 TERMINALS


MARK PAIR NO'S WITH SOFT LEAD PENCIL
ERASE WITH RUBBER TIP OF PENCIL
OR MOISTENED FINGERS
BLACK PUTTY

NOTE:
USE JUNCTION BOX WRENCH ON THE TERMINALS.
REMOVE PUTTY ONLY TO INSERT WIRES.

FIG. 7—Wiring diagram of cable terminal

rear walls of the most substantial buildings. Around the interior walls at a height preferably not over ten feet from the ground are cleated lead-covered dry-core cables. At intervals of 100 to 200 feet a multiple tap is taken to terminal boxes. From these terminal boxes No. 18 B. & S. gauge rubber-covered and braided-bridling wire is carried through bridling rings spaced about four feet apart to the various entrances to the subscribers' premises. This distributing cable is of course connected to an underground cable from the main subway. In case the number of telephones within the block is small, a terminal box at the end of the underground cable may be sufficient, and nothing but bridling wires through rings used for distribution purposes. Since no protection is needed between the distributing lines and the underground cable, a very neat form of terminal box may be used. The type of box which is being largely used for this service at the present time is shown in Figs. No. 5, 6, and 7. In this box the wire terminals are mounted on hard-burned porcelain. A five-foot length of dry-core lead-covered cable is connected to the terminals on the porcelain blocks, after which the blocks are firmly seated on a gasket of wicking saturated in compound. The cast iron retaining case is then filled with compound, the cable wiped to a brass nipple, and an air-tight plug inserted in the top. This hermetically seals the terminal. On account of the durable nature of the materials employed in the construction of this terminal; namely, porcelain, cast iron and brass, the depreciation and maintenance should be very low.

In Figs. 8, 9, 10, 11 are shown examples of interior block distribution. This type of construction is so inconspicuous as to be rarely objectionable, and in consequence its use should be adopted wherever possible. In certain districts in the neighborhood of underground subways, the buildings may be very old or may be very widely scattered. In these cases an interior block system could not be installed to advantage, and a low ring-top distributing pole should be used pending the time the block will be sufficiently built up to permit of direct connection or interior block wiring. Figs. 12 and 13 show examples of this type of construction. Distributing poles are useful for furnishing connection between the underground system and the subscribers' premises during a period when direct connection or interior block wiring is not warranted. Ultimately, it seems certain that the distributing pole is bound to go.

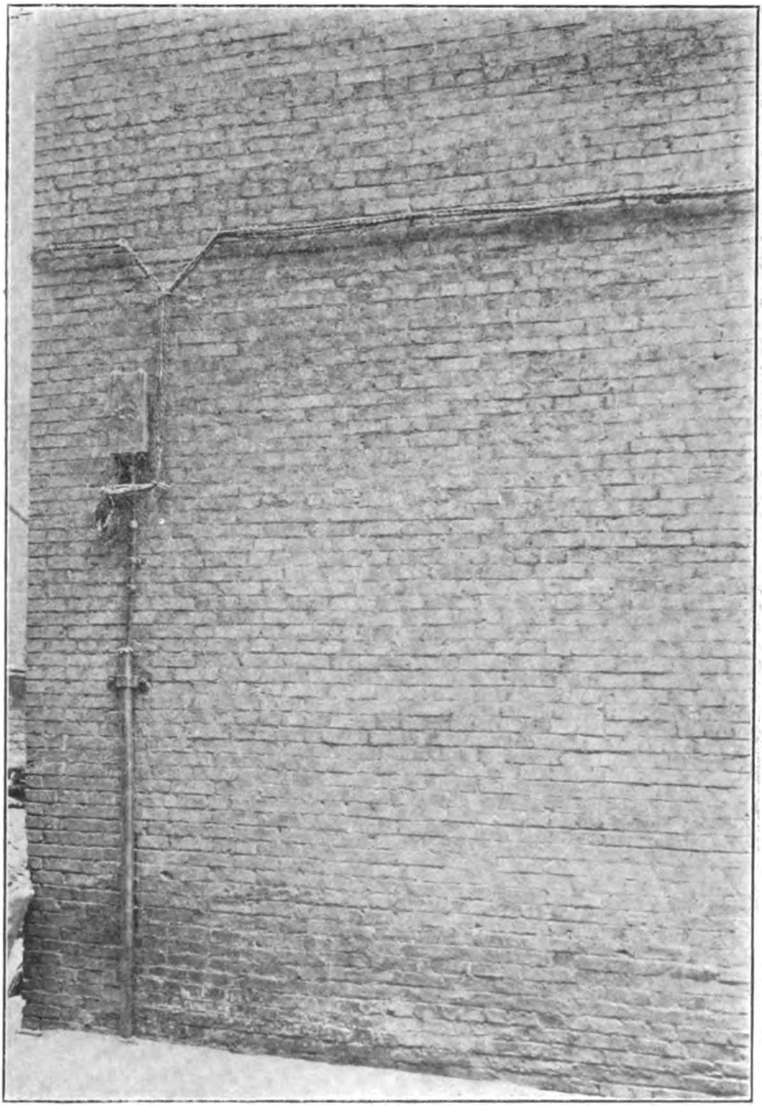


FIG. 8—Interior block distribution Sub-duct cable terminal and wiring runs

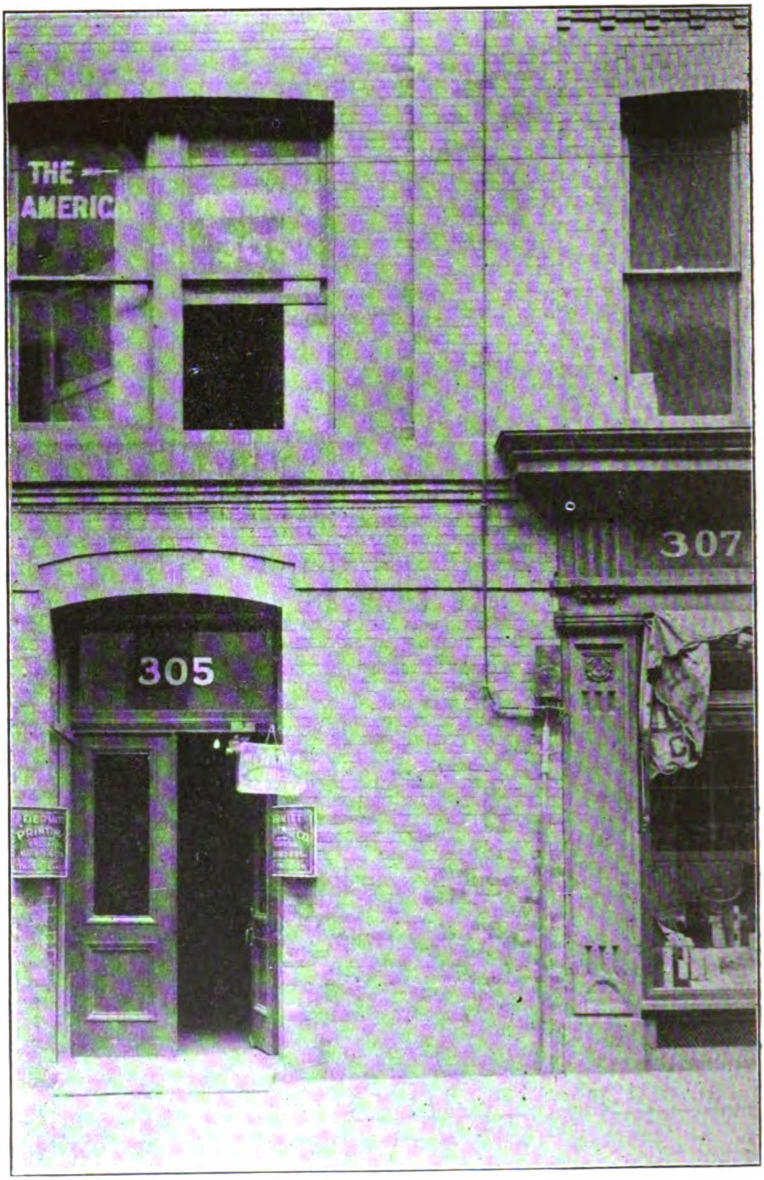


FIG. 9—Interior block distribution Example of wiring run to upper floors of building

A very large proportion of telephone service must be given in scattered residence districts where the number of circuits is so small as not to justify conduit construction. If conduits were installed at once, the construction plant costs would be very materially increased and consequently the cost of service to the subscribers would have to be increased. It is therefore necessary to determine what is the most economical, efficient, and sightly form of aerial distribution. In the early days of the telephone it was but natural that the distribution of the telephone wires should follow the same practice adopted by the telegraph companies. Very soon it was found that the number of telephone wires multiplied very rapidly, which required towering poles, equipped sometimes with as many as twenty cross-arms. The invention of the dry, core-lead cable furnished relief for these lines, although for many years it was the custom to use as much open wire and as little cable as possible.

In the territory about Pittsburg the topography of the ground is exceedingly rough. This results in winding streets and almost an entire absence of alleys. To construct very large open wire lines in these winding streets was early seen to be impracticable, and when the great expansion of the telephone business began in 1897 it became imperative to design other methods for aerially distributing telephone lines. The system which was finally worked out and decided upon is that known as the aerial cable or all-cable system which was adopted in 1897 and has been our standard type of aerial construction ever since. In this system, very low poles are used, rarely exceeding 30 to 35 feet in height. These distributing lines are placed in alleys if they are available. A cable is strung near the tops of the poles and on alternate poles are placed 10- or 15-pair terminals. Each pair in the distributing cable appears in from two to four terminals, and common pairs are so laid out in adjacent terminals that it is easy to provide for party lines. The multiplying is so arranged that when the cable becomes crowded it may be cut into two or four parts, all pairs appearing in each part, and relieved by feeder cables. No cross-arms or bare wires are used for distribution along the lead, but from the binding-posts in the cable terminal a twisted pair, rubber-covered, and braided wire is strung directly to a point within the subscriber's premises. The use of this well insulated twisted pair wire very materially reduces the maintenance. An aerial cable system of

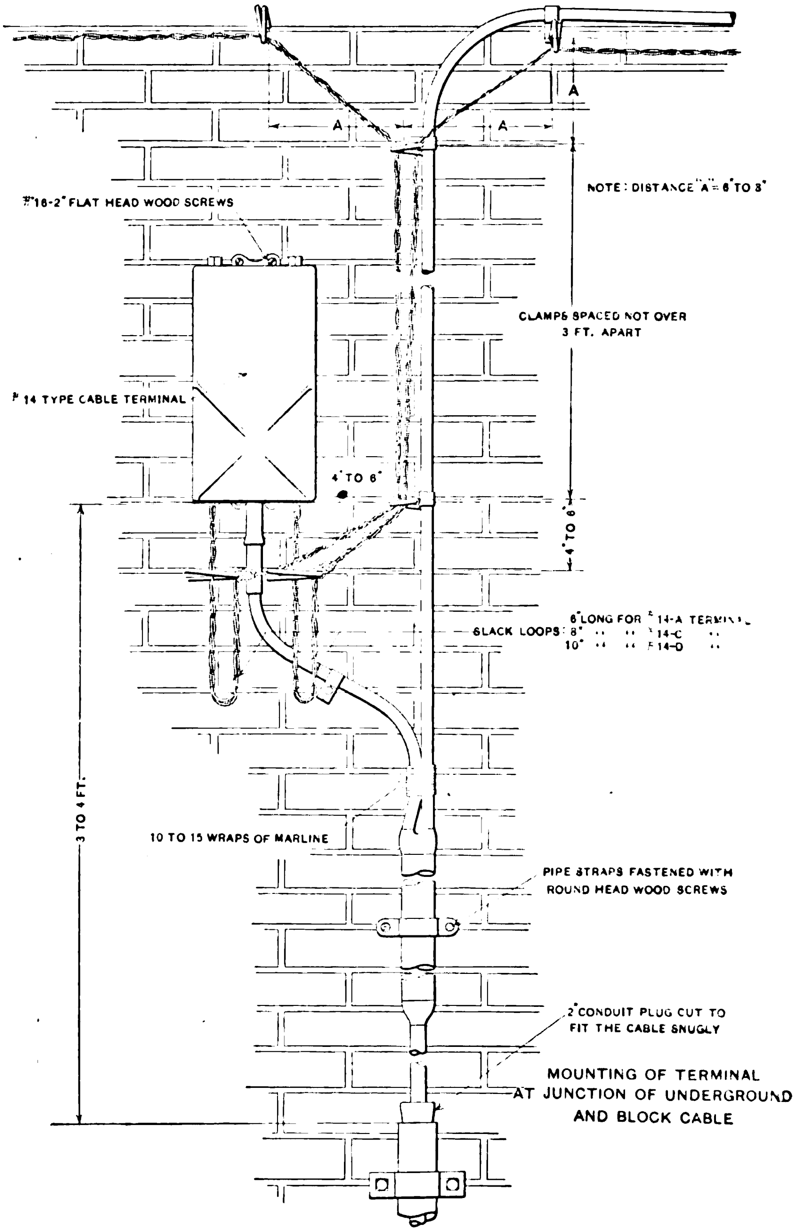


FIG. 10—Interior block distribution. Details of cable terminal-connections on wall of building

this kind with twisted pair wires leading directly to the subscribers' houses is undoubtedly the most sightly form of aerial distribution, since all the cumbersome and troublesome open wires are done away with. In Figs. 14, 15, 16, 17, and 18 are shown methods and materials used in aerial cable construction. Attention is called to the grooved insulators used for supporting the twist wires. Each wire of the pair occupies a separate groove, thus preventing a crossing of the wires, which sometimes injures the insulation when there is a heavy strain on the wires.

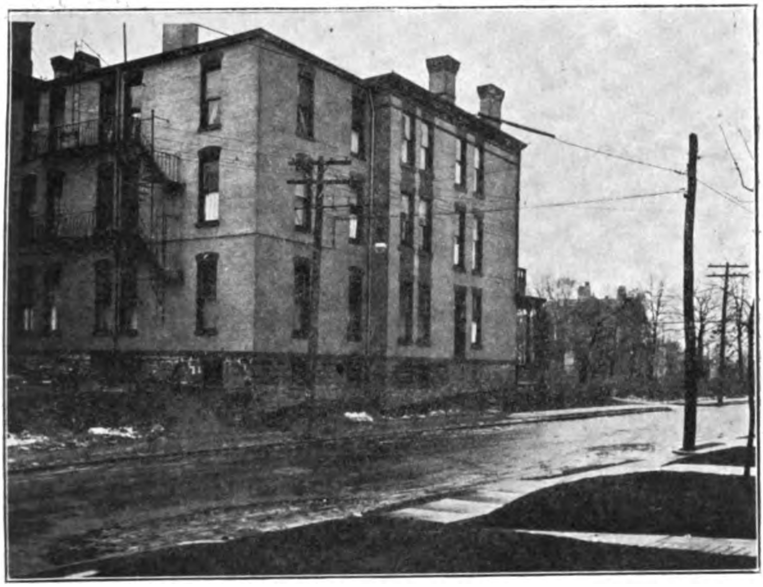


FIG. 11—Interior block distribution Suspending wires from building to ærial cable terminal on pole

There has been considerable discussion among engineers regarding the life of twisted-pair, rubber-covered distributing wire. Rubber and paint are somewhat alike, in that all kinds of mixtures are sold under their names. From the very beginning we have been careful to specify a reasonably high grade of rubber and to insist on making tests of all wire submitted to us, to be sure that our specifications have been complied with. Very good wire was thus obtained, and samples which we now take down after having been in use for seven to nine years still show an insulation resistance of 200 to 400 megohms per mile when submerged in water. If the ordinary type of market wire, which is mainly intended for inside wiring, is used, the life will be much shorter. A good quality of rubber distributing wire well protected with a heavy braid should prove serviceable for ten or fifteen years.

Until recently the type of distributing wire most generally used was made of No. 14 B. & S. gauge copper. This size of wire was not necessary for conductivity, for as a rule it was connected to a 22- or 19-gauge cable pair. This size of wire was required for mechanical strength, because the wire was strung in spans and had to be self-supporting. During the past year there has been put on the market a copper-clad steel wire which is made by a new method. Copper is welded to a steel ingot and the copper and steel drawn out uniformly together. From all the examinations we have been able to make it seems that there is a perfect union between the copper and the steel. A No. 17 B. & S. gauge copper-clad wire having

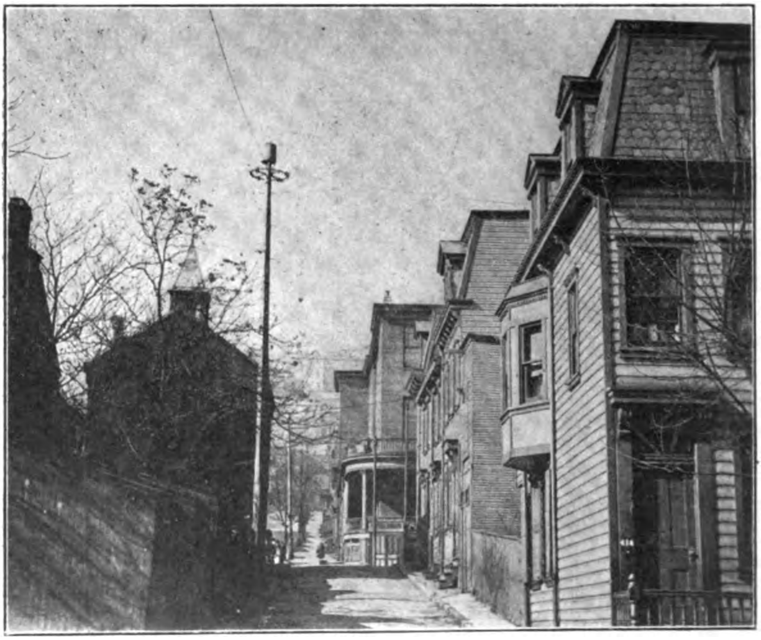


FIG. 12—Distribution of subscriber's lines from circle tap distributing pole

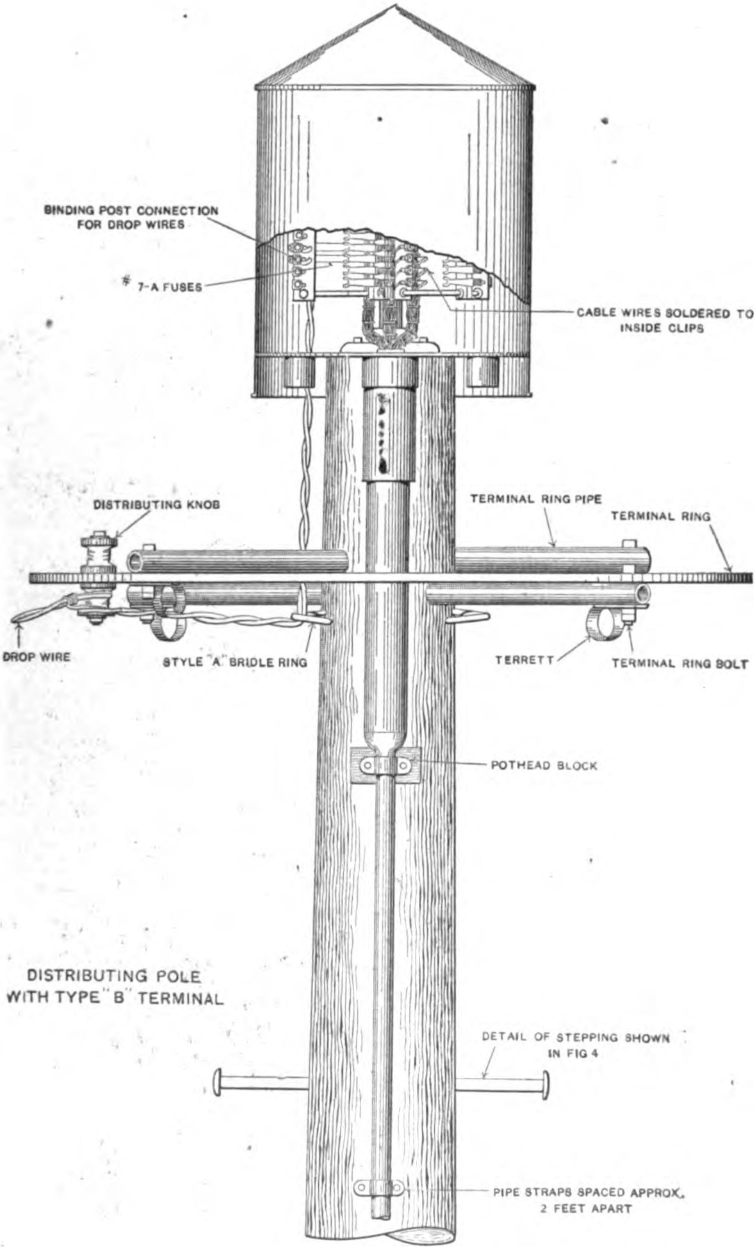

BINDING POST CONNECTION FOR DROP WIRES
# 7-A FUSES
CABLE WIRES SOLDERED TO INSIDE CLIPS
DISTRIBUTING KNOB
TERMINAL RING PIPE
TERMINAL RING
DROP WIRE
STYLE "A" BRIDLE RING
TERRETT
TERMINAL RING BOLT
POTHEAD BLOCK
DISTRIBUTING POLE WITH TYPE "B" TERMINAL
DETAIL OF STEPPING SHOWN IN FIG 4
PIPE STRAPS SPACED APPROX. 2 FEET APART

Fig. 13—**Details of circle top distributing pole**

30% conductivity of copper has the same tensile strength as a No. 14 B. & S. hard-drawn copper wire. This reduces the amount of material in the distributing wire one-half, and what

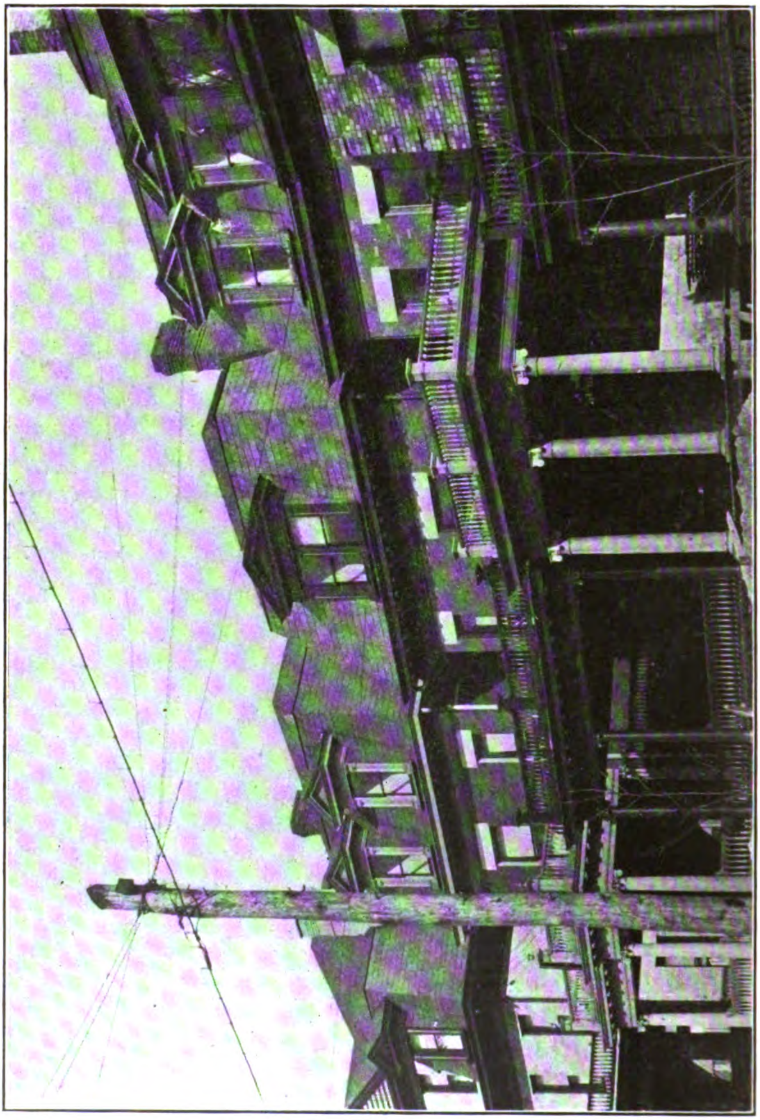


FIG. 14—Aerial cable distribution Cable top and drop wires to residences

is still more important, on account of the reduced area, decreases the amount of expensive rubber compound required to surround the wire. The amount of braided covering is also materially reduced. The finished wire is very light and easy to handle and costs approximately 30% less than the No. 14 B. & S. type of wire.

At first sight it seems that a terminal on alternate poles must be expensive, and that terminals farther apart and with intervening distribution made by bare wire, would be cheaper. In order to determine this point clearly, a study was made some time ago showing a comparison between aerial cable distribution with taps on alternate poles and with twisted pair direct to the houses, as compared with aerial cable supplemented with bare-wire distribution. Various densities of telephone distribution were assumed, and it was found that in nearly all cases the system with taps on alternate poles was not only cheapest in first cost but also in annual charges. Where the distribution was very dense it was found that a tap on every pole was the most economical. As a general principle it would seem that we should carry the telephone circuits just as far as possible in cable and make the subscriber's drop of minimum length.

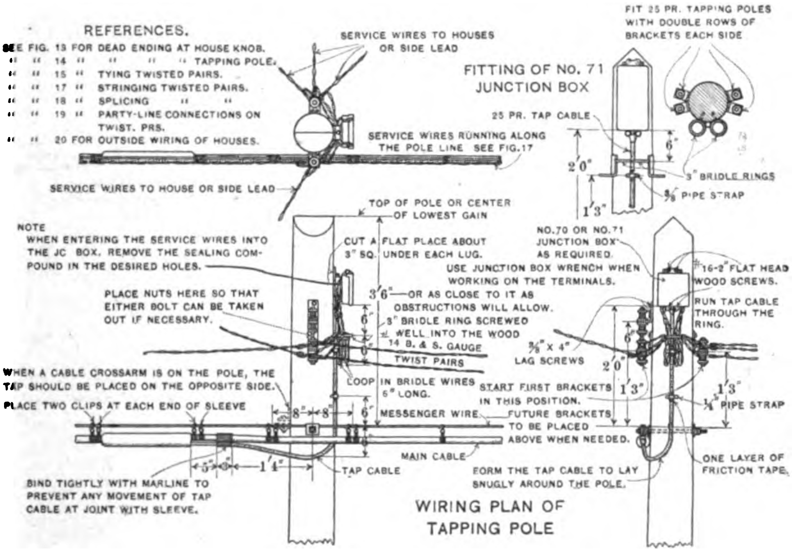

REFERENCES.
SEE FIG. 13 FOR DEAD ENDING AT HOUSE KNOB.
" " 14 " " " " TAPPING POLE.
" " 15 " TYING TWISTED PAIRS.
" " 17 " STRINGING TWISTED PAIRS.
" " 18 " SPLICING " "
" " 19 " PARTY-LINE CONNECTIONS ON TWIST. PRS.
" " 20 FOR OUTSIDE WIRING OF HOUSES.
SERVICE WIRES TO HOUSES OR SIDE LEAD
SERVICE WIRES RUNNING ALONG THE POLE LINE SEE FIG.17
SERVICE WIRES TO HOUSE OR SIDE LEAD
FITTING OF NO. 71 JUNCTION BOX
FIT 25 PR. TAPPING POLES WITH DOUBLE ROWS OF BRACKETS EACH SIDE
25 PR. TAP CABLE
6"
2'0"
1'3"
3" BRIDLE RINGS
⅜ PIPE STRAP
TOP OF POLE OR CENTER OF LOWEST GAIN
NOTE
WHEN ENTERING THE SERVICE WIRES INTO THE JC BOX, REMOVE THE SEALING COMPOUND IN THE DESIRED HOLES.
CUT A FLAT PLACE ABOUT 3" SQ. UNDER EACH LUG.
NO.70 OR NO.71 JUNCTION BOX AS REQUIRED.
USE JUNCTION BOX WRENCH WHEN WORKING ON THE TERMINALS.
#16-2" FLAT HEAD WOOD SCREWS.
PLACE NUTS HERE SO THAT EITHER BOLT CAN BE TAKEN OUT IF NECESSARY.
3'6"—OR AS CLOSE TO IT AS OBSTRUCTIONS WILL ALLOW.
6"
3" BRIDLE RING SCREWED WELL INTO THE WOOD
14 B. & S. GAUGE TWIST PAIRS
⅜" x 4" LAG SCREWS
RUN TAP CABLE THROUGH THE RING.
6"
2'0"
1'3"
1'3"
¼" PIPE STRAP
WHEN A CABLE CROSSARM IS ON THE POLE, THE TAP SHOULD BE PLACED ON THE OPPOSITE SIDE.
LOOP IN BRIDLE WIRES 6" LONG.
START FIRST BRACKETS IN THIS POSITION.
PLACE TWO CLIPS AT EACH END OF SLEEVE
8"
8"
6"
MESSENGER WIRE
FUTURE BRACKETS TO BE PLACED ABOVE WHEN NEEDED.
5"
3"
1'4"
MAIN CABLE
TAP CABLE
ONE LAYER OF FRICTION TAPE.
FORM THE TAP CABLE TO LAY SNUGLY AROUND THE POLE.
BIND TIGHTLY WITH MARLINE TO PREVENT ANY MOVEMENT OF TAP CABLE AT JOINT WITH SLEEVE.
WIRING PLAN OF TAPPING POLE

FIG. 15—Details of construction at branch terminal pole

There will, of course, be many streets and districts where for the present time aerial cable is not warranted. If these districts are in the neighborhood of an aerial cable base line, and the subscribers are not located more than 1000 feet away from the cable line, it is economy to connect them with twisted, pair wire strung on distributing brackets rather than to resort to the use of bare wire and cross-arms, where perhaps a large part of the arm capacity will lie idle for several years. This method of wiring is shown in Fig. 19. If the side streets are clear of trees and it appears probable that many of the circuits will be more than 1000 feet long, the distribution should be made by means of bare wire on cross-arms, as shown in Fig. 20. Generally speaking, the bare wire on these side lines should

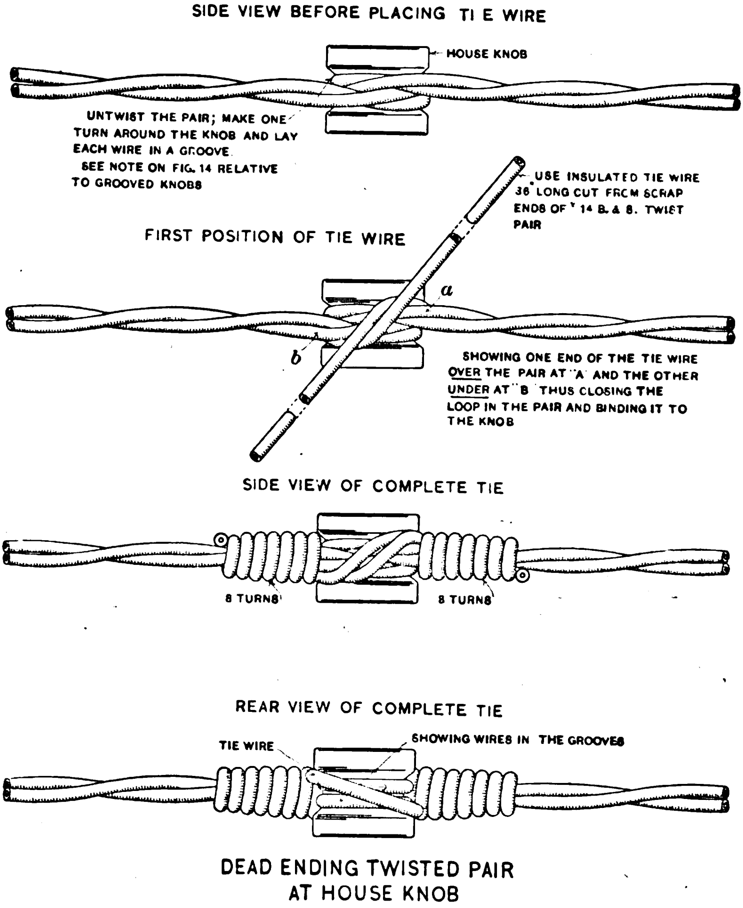

SIDE VIEW BEFORE PLACING TIE WIRE
HOUSE KNOB
UNTWIST THE PAIR; MAKE ONE TURN AROUND THE KNOB AND LAY EACH WIRE IN A GROOVE.
SEE NOTE ON FIG. 14 RELATIVE TO GROOVED KNOBS
FIRST POSITION OF TIE WIRE
USE INSULATED TIE WIRE 36" LONG CUT FROM SCRAP ENDS OF # 14 B. & S. TWIST PAIR
a
b
SHOWING ONE END OF THE TIE WIRE OVER THE PAIR AT "A" AND THE OTHER UNDER AT "B" THUS CLOSING THE LOOP IN THE PAIR AND BINDING IT TO THE KNOB
SIDE VIEW OF COMPLETE TIE
8 TURNS
8 TURNS
REAR VIEW OF COMPLETE TIE
TIE WIRE
SHOWING WIRES IN THE GROOVES
DEAD ENDING TWISTED PAIR
AT HOUSE KNOB

FIG. 16—Method of tying twisted pair insulated wires to porcelain knobs

be of copper, for at the present time with so much sulphurous smoke in the atmosphere of our cities and towns, the life of iron wire is too short to give the wire serious consideration. Copper wire smaller than No. 14 N. B. S or No.

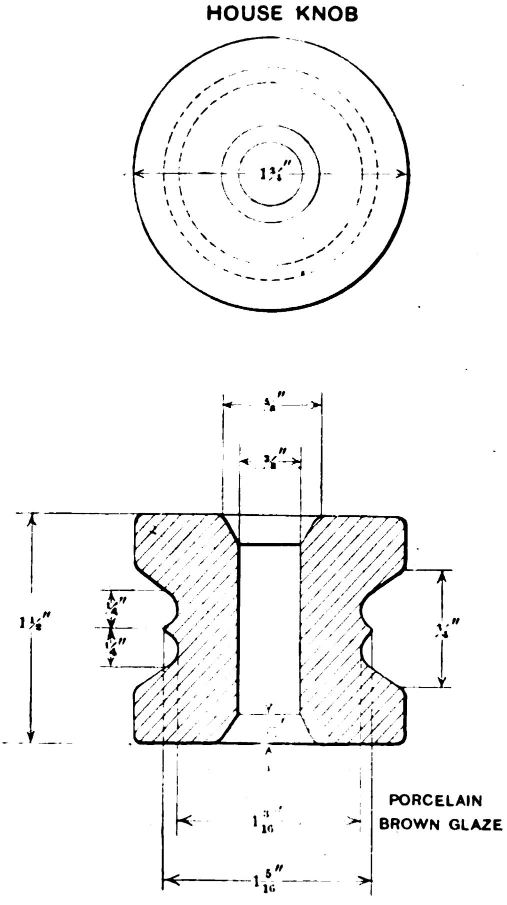


FIG. 17—Porcelain knob used for attaching twisted pair drop wires to houses

12 B. & S. gauge cannot safely be used in spans because of of its low tensile strength. This size of wire is not required for conductivity, since in the places where this wire is usually strung we would be satisfied with a cable conductor of 19 or 22 gauge. Here again it also seems possible to make considerable

saving by the use of copper-clad steel wire. A No. 14 B. & S. or No. 16 N. B. S. copper-clad wire is sufficiently strong mechanically and has a conductivity equivalent to a 19-gauge cable pair. This will reduce the first cost of line wire about one-half. The copper-clad wire will be just as durable as copper, and since its strength lies on the inside rather than in the hardened outside shell, it will be subject to a lesser number of breaks and besides it can be taken down and used in other places. It is usually necessary to scrap copper wire when taken

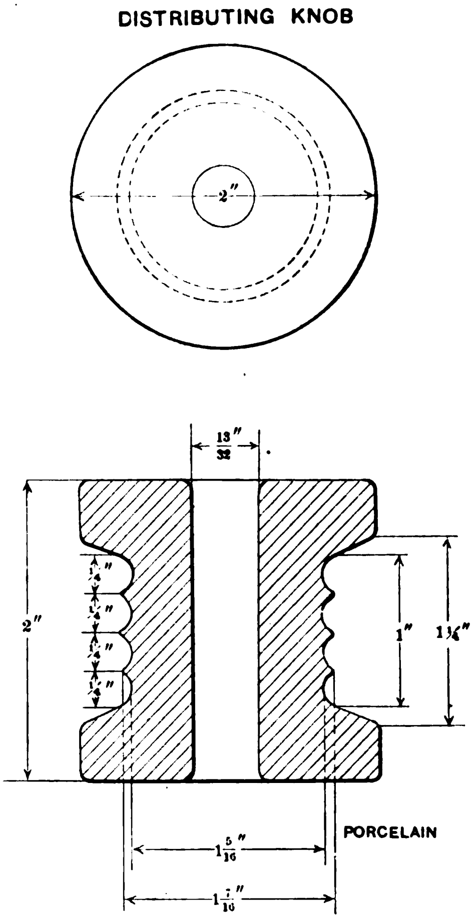
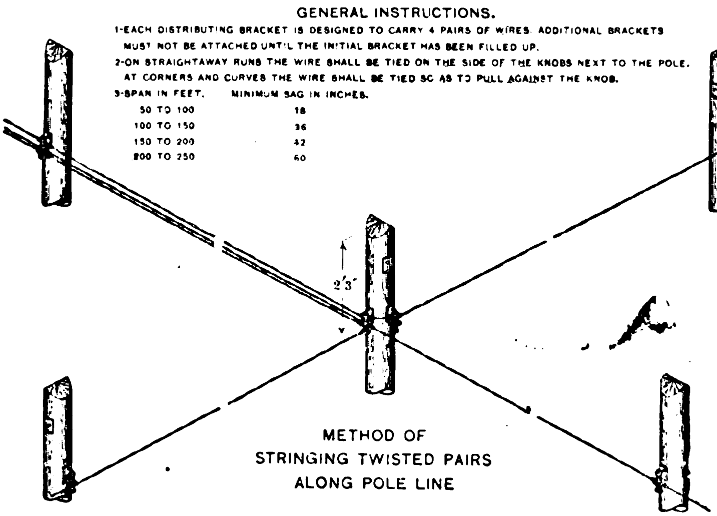


FIG. 18—Porcelain knob used for attaching twisted pair drop wires to poles

down, for as a rule it will not stand re-stringing in another location without causing much trouble from breaking, due to nicked and scratched spots.

When the open-wire subscribers' circuits fills several cross-arms, it is generally economical to replace them with a cable. From studies which we have made it has been found that when a cable is placed on a lead of this character, it is economy to remove the open wires and cross-arms and return them to stock rather than attempt to use them for distribution from taps placed one to two blocks apart on the cable. The removing of open wires when the cable is placed cleans up the line in good shape, makes it easy to maintain, and far more sightly to the public. It would seem that the aerial cable system of distribution of telephone lines is the most ideal system now known for districts where for the present conduits are not justified. Practically all the large telephone companies have realized the economies to be obtained by its use, and during the last three years thousands of miles of this kind of cable distribution have been placed.


GENERAL INSTRUCTIONS.

1-EACH DISTRIBUTING BRACKET IS DESIGNED TO CARRY 4 PAIRS OF WIRES. ADDITIONAL BRACKETS MUST NOT BE ATTACHED UNTIL THE INITIAL BRACKET HAS BEEN FILLED UP.

2-ON STRAIGHTAWAY RUNS THE WIRE SHALL BE TIED ON THE SIDE OF THE KNOBS NEXT TO THE POLE. AT CORNERS AND CURVES THE WIRE SHALL BE TIED SO AS TO PULL AGAINST THE KNOB.

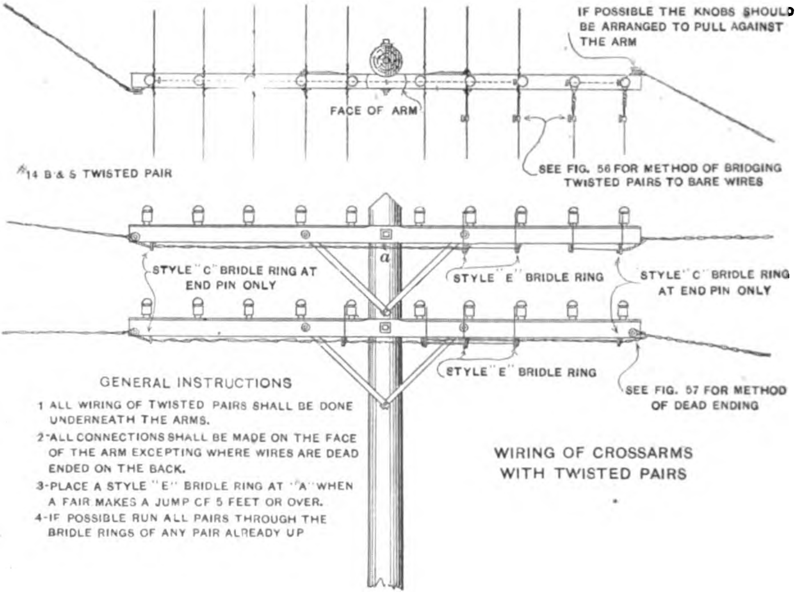
3-SPAN IN FEET.	MINIMUM SAG IN INCHES.
50 TO 100	18
100 TO 150	36
150 TO 200	42
200 TO 250	60

FIG. 19—Method of stringing twisted pair wires along a pole lead

Since the wire plant requires the major portion of the money expended for a telephone system, and since there are so many varied and complex factors entering into its design, the greatest care should be given to its engineering. The most important problems in connection with the wire plant are:

1. The development plans which must be carefully worked out by the engineer so that not only the first cost of the plant will be a minimum, but so that the plant can take care of increases in business from time to time without unnecessarily large expenditures for redesign and reconstruction.

2. The transmission must be carefully studied so that there will be a good volume of talk between any two connected


IF POSSIBLE THE KNOBS SHOULD BE ARRANGED TO PULL AGAINST THE ARM
FACE OF ARM
#14 B & S TWISTED PAIR
SEE FIG. 56 FOR METHOD OF BRIDGING TWISTED PAIRS TO BARE WIRES
a
STYLE "C" BRIDLE RING AT END PIN ONLY
STYLE "E" BRIDLE RING
STYLE "C" BRIDLE RING AT END PIN ONLY
STYLE "E" BRIDLE RING
SEE FIG. 57 FOR METHOD OF DEAD ENDING

GENERAL INSTRUCTIONS

1 ALL WIRING OF TWISTED PAIRS SHALL BE DONE UNDERNEATH THE ARMS.
2-ALL CONNECTIONS SHALL BE MADE ON THE FACE OF THE ARM EXCEPTING WHERE WIRES ARE DEAD ENDED ON THE BACK.
3-PLACE A STYLE "E" BRIDLE RING AT "A" WHEN A FAIR MAKES A JUMP CF 5 FEET OR OVER.
4-IF POSSIBLE RUN ALL PAIRS THROUGH THE BRIDLE RINGS OF ANY PAIR ALREADY UP

WIRING OF CROSSARMS WITH TWISTED PAIRS

Fig. 20—Distribution of subscriber's lines by means of open wire on cross-arms Twisted pair drops to subscriber's premises

subscribers. The circuits, whether in cable or in open wire, should be graded and if necessary loaded so that while the transmission is sufficiently good it will not be given over unnecessarily expensive trunk lines.

3. The underground system must be extended as rapidly as it is economical to do so, and direct terminal or interior block connections made with the maximum number of subscribers.

4. In the outlying districts where pole lines will still be

resorted to, every effort must be made so to design and construct these lines as to have them of low first cost and annual charges. They must be but slightly affected by the elements and free from interference from electric light and power circuits. These aerial systems must be made sightly to avoid the criticisms of the public.

5. The engineer must constantly seek for new and improved types of material and construction methods to be used in the wire plant so that the first cost and maintenance can be reduced.

A paper presented at the 218th Meeting of the American Institute of Electrical Engineers New York, April 26, 1907.

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(*Subject to final revision for the Transactions.*)

LIGHT FROM GASEOUS CONDUCTORS WITHIN GLASS TUBES—THE MOORE LIGHT

BY D. MCFARLAN MOORE

All energy consists of vibratory or wave motion. It can be conveniently classified under six general heads: mechanical motion, sound, heat, electricity, light, chemism.

The term "light" should be used, not as the name of an effect on the eye, but to designate one of the great divisions of all energy. Each division always contains a percentage of all the other divisions, and the less this percentage the purer is the division sought after. The less heat, etc., light contains the more efficient we call it. Science should know how efficiently to change or convert any one of these divisions into any other one. For example, we do know how efficiently to change electricity into mechanical motion; namely, by the use of an electric motor, but we are ignorant concerning many of the other 29 combinations, which indicates that there remains plenty of scientific work to be done by future generations.

Since all energy is really the same thing, we should become proficient in magnifying or suppressing, at will, any particular division or divisions, corresponding with rate of vibrations which we have settled upon and named because they effect in a distinctive manner the different organs of our bodies.

Some years have passed since I first realized that there then existed no form of artificial light that could truthfully be said to imitate daylight. Believing unalterably that such a light was to be the next logical step of great importance in artificial illumination, I commenced an investigation that still continues.

To duplicate daylight closely, three premises were soon determined upon which have never been abandoned:

1. Large light source, the practical solution being a long glass tube emitting light.
2. Use electricity flowing through a gaseous-conductor, not a solid conductor.
3. Perfect imitation of color values.

Immediately on beginning investigation on these premises, the gaseous-conductor became the factor of greatest importance. The life of the first lamps or tubes constructed was extremely short, since, as then expressed, "the vacuum deteriorated" Up to date, four methods made have been developed and used and thousands of experiments have been made concerning the replenishing of the gas and thereby overcoming this vital difficulty of the gaseous-conductor becoming non-conducting, due to the peculiar chemical reaction that must occur when electricity passes from a solid conductor to a gaseous-conductor. These methods are as follows:

1. By obtaining a cycle of events through catalytic action. The intensity of light possible was found to be very low.
2. Obtaining a cycle by evaporation and condensation. Probably mercury is the only element that can ever be used in this way in glass tubes.
3. By re-supplying the necessary gases automatically by the action of heat on suitable substances.
4. By automatically feeding gas to the tube when needed, which is the method used at the present time.

Inventing intricate theories for explaining vacuum-tube phenomena was easy compared with furnishing a merchant a practical tube light to sell his goods under. For some years past there has existed a great mass of theoretical literature on gaseous conduction etc., but practically none that dealt with watts and hefners under commercial conditions. The old "pith-ball" phenomena of elementary physics is still a good working hypothesis for explaining the passage of electricity through gases, especially at less than atmospheric pressures. It is apparent that movements of the almost infinitely small "pith-balls" or ions is regulated largely by the potential and degree of vacuum. A collision of two moving bodies results in heat. The general law of all light sources applies also to the vacuum-tube light: namely, the higher the temperature the greater the efficiency. The absolute temperature of the individual particles of matter within the tube after collision is greater than that of any other temperature on earth. But the quantity of heat of each of these ultra incandescent, though infinitesimal, bodies, is so small that there results that which at first would seem paradoxical: namely, the " coldest " source of light. In this expression we crudely refer to the external temperature of the entire tube. Some gases are easily ionized and conduct well, yet give practically no light, which may indicate that their chemical constituency and therefore their emissivity is not suitable for light production.

In two previous papers which I had the honor to present to this Institute*, certain statements were made as to what would probably be the system of illumination which would finally, in great measure, supplant the systems then and now existing. The subject of improved artificial lighting methods is one of the greatest economic problems of the day. Time and space will not permit in this paper a historical review either of these investigations or of the art as a whole. The way has been long and strenuous, but always interesting. Careless criticism has been plentiful and professional support rare. The system herein described has become known as the " Moore Light " and therefore I trust you will pardon, on simply the ground of expediency and brevity, my reference also to it by that name, there being no alternative.

The present system has passed the experimental stage. It is a result of twelve years of experimenting, but its advance from year to year has always been steady. It is now fitting that an authoritative technical record be made of the essential facts at present connected with it. At the outset I venture to assert that if one thoroughly versed in the art of illumination should formulate entirely on theoretical lines complete, ideal specifications for an artificial illuminating system, that he would unconsciously describe the essential features of the lighting system described in this paper. It contains no " make and break " apparatus whatever.

For many years all scientists have agreed that a vacuum-tube light would be right theoretically: commercial men who have had their electric lighting bills reduced now know of its practical value.

The illumination of this assembly room, Fig. 1, at the present moment by a so-called Moore vacuum tube, greatly facilitates making clear not only its mechanical construction, but also its many other salient advantages and characteristics. The electrical energy is obtained from the alternating-current street mains.

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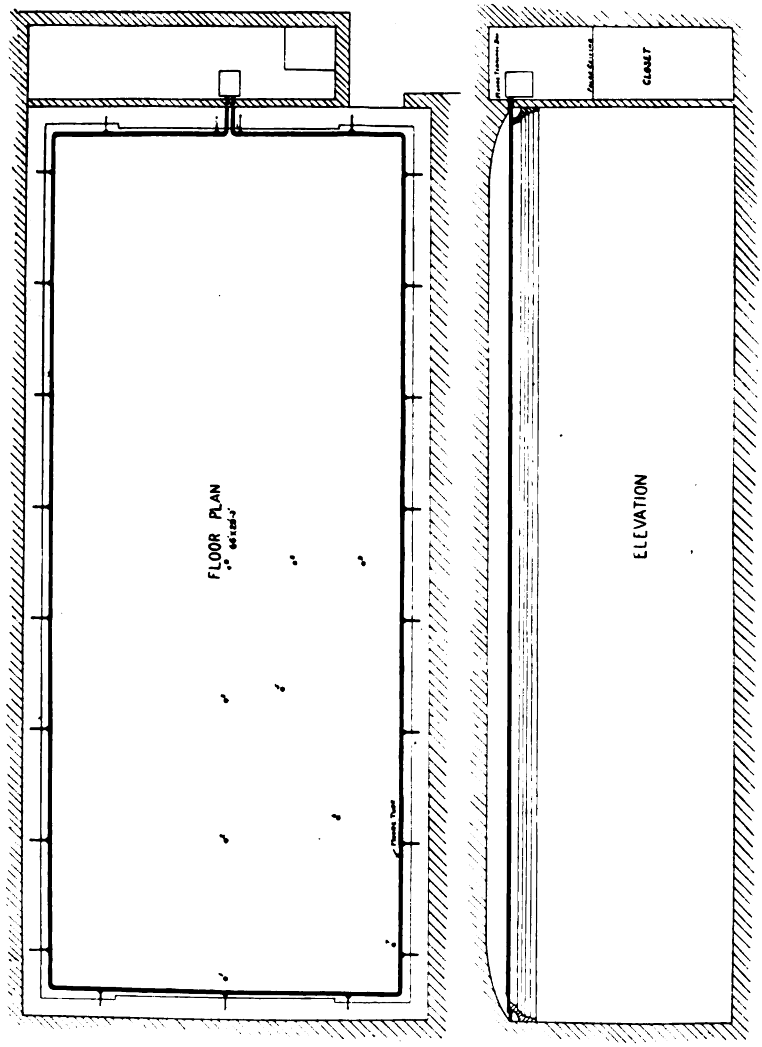
* " A New Method for the Control of Electric Energy," September 20, 1893; " Recent Developments in Vacuum Tube Lighting," April 22, 1896.

It will be noted that the light emenates with absolute uniformity from the entire area of a single, continuous glass tube 1.75 in.



Figs. 1 and 2

in diameter in the form of a large rectangle 62 ft. by 25 ft. which is supported on the cove designed to conceal the incandescent lamps. The glass tube is 13 in. from the ceiling and 16 ft. from the floor, as shown by Fig. 2.

It is supported by plain brass rings 1$\frac{7}{8}$ in, in diameter attached to small procelain insulators inserted in the ends of brass fixture tubing which of course contains no wires.

The two ends of this continuous tube at the center of the rear side of the rectangle approach within such a short distance of each other that the gap is scarcely discernable from the floor.

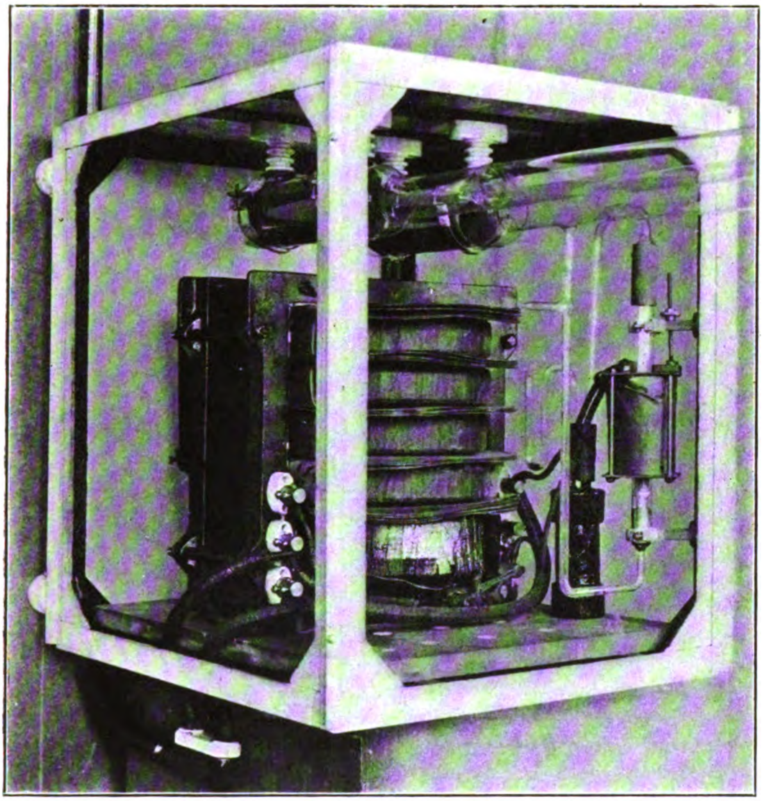


FIG. 3—Interior of terminal box

They then extend horizontally through the wall and into a rigid steel terminal-box located on the wall of the closet at the rear of the hall. This terminal-box contains all the necessary electrical apparatus and corresponds in form and size with that shown in Fig. 3. It is fed by 60-cycle alternating current at 220 volts. Besides the two carbon electrodes of the tube, the terminal-box contains a step-up transformer and a small specially designed valve with its solenoid, which represents an entirely new departure in vacuum tube lighting and also one that is vital to its success. The electrical circuits from this apparatus are extremely simple and are shown in Fig. 4. There is no distributed or high-potential wiring. The high-potential terminals of the transformer within the terminal-box are only two or three inches in length and are attached directly to the electrodes within the box. All the high-potential wires, therefore, always remain within the box which has a wire seal placed upon it. A hand can be placed on each of the glass tubes near where they emerge from the two holes in the side of the box, but the glass tubes insulate the gaseous-conductor within them so well that no shock can be felt.

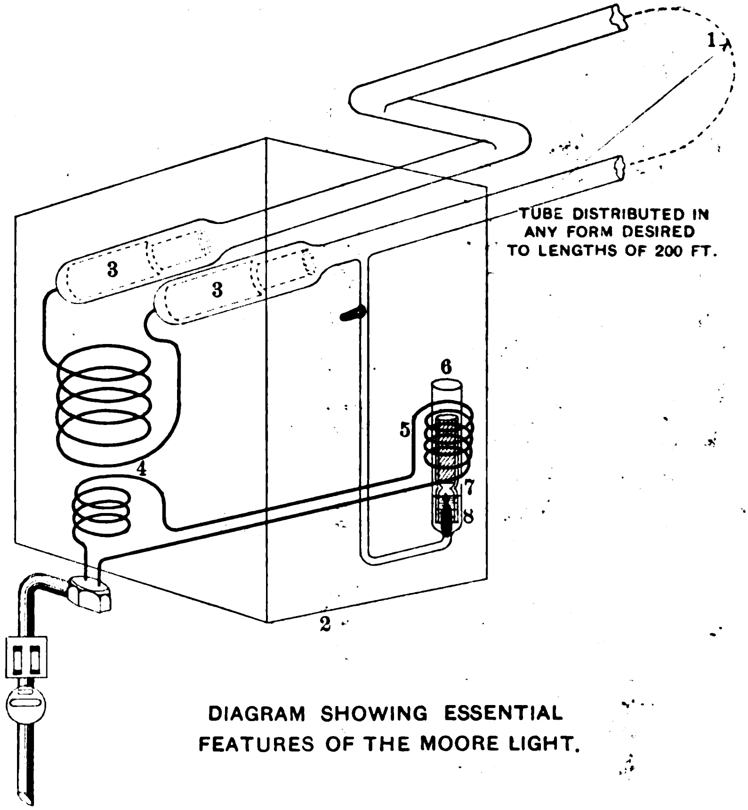


DIAGRAM SHOWING ESSENTIAL FEATURES OF THE MOORE LIGHT.

Fig. 4

Since the feeder-valve operated by the solenoid just mentioned is an essential feature of this system, a description of its operation will be interesting. Any vacuum tube when commercially luminous will, in a few minutes, seriously alter the degree of its vacuum unless special provision be made to replenish its gaseous-conductor. Due to the flow of current, a portion of the residual gas within the tube is absorbed; that is, changed to a solid form, and thereby the degree of vacuum in the tube becomes higher.

This higher degree of vacuum so increases the resistance of the tube that at first the light simply becomes unsteady but rapidly changes to a condition of violent spasmodic flickering, which soon entirely ceases and the tube gives no light whatever. The light has actually died for want of air. This simple fact was not recognized for many years by prominent investigators in this line of phenomena. The problem, therefore, was to devise thoroughly practical means for replenishing the gaseous-conductor of a vacuum tube. This is the function of the feeder-valve which permits air or other gas to enter the tube only when it is needed and in such a manner that it is entirely automatic. A piece of ⅞ in. glass tubing is supported vertically, see Fig. 5, its bottom end is contracted into a ⅜ in. glass tube which extends to the main lighting tube. At the point of contraction at the bottom of the ⅞ in. tube there is sealed by means of cement a ¼ in. carbon plug, the porosity of which is not great enough to allow mercury to percolate through it but which will permit gases easily to pass, due to the high vacuum of the lighting tube connected to the lower end of the plug, and approximately atmospheric pressure above it. This carbon plug is normally completely covered with what would correspond to about a

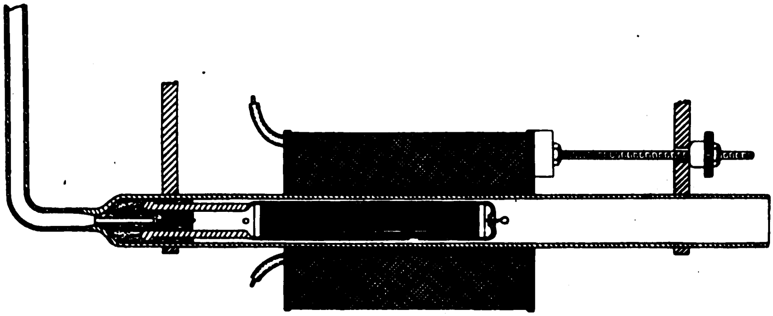


FIG. 5—Feeder-valve

thimbleful of mercury which simply seals the pores of the carbon plug, and therefore has nothing whatever to do with the conducting properties of the gas in the main tube which produces the light. Partly immersed in the mercury and concentric with the carbon plug, is another smaller and movable glass tube, the upper end of which is filled with soft iron wire, which acts as the core of a small solenoid connected in series with the transformer. The action of the solenoid is to lift the concentric glass tube partly out of the mercury, the surface of which falls and thereby causes the minute tip of the conical shaped carbon plug to be slightly exposed for a second or two.

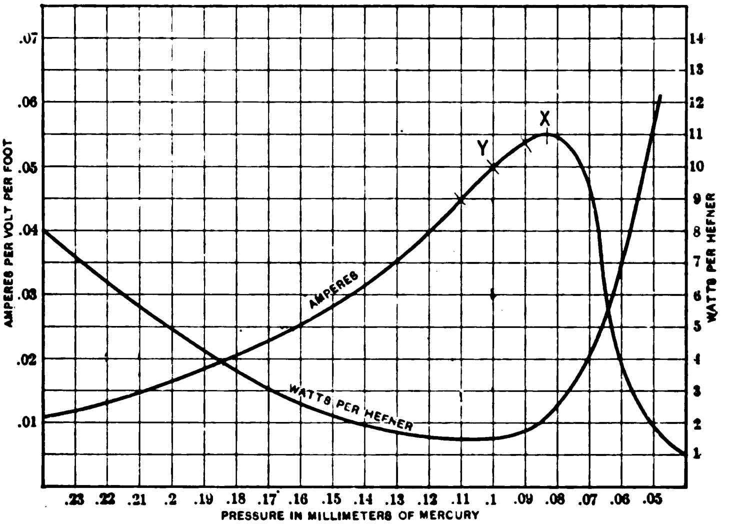


Fig. 6.

and an extremely small quantity of air or other gas filters through it and then finds its way into the vacuum tube proper. In normal operation, most of the tubes expose this carbon tip for about one second every minute. Therefore, this system, broadly speaking, consists in continuously burning air electrically.

Fig. 6 will explain the theory of this action still more clearly. This curve shows the relation between conductivity and degree of vacuum. Of course there must be a critical degree of vacuum at which the conductivity is a maximum; this point corresponds to *X*. By means of the adjusting screw at the top of the solenoid the degree of vacuum is kept normally at a lower vacuum corresponding with *Y*, therefore as the electricity uses up the gaseous-conductor, the vacuum of course becomes higher, the conductivity better, and a greater current flows through the solenoid causing it to lift the displacer and expose the carbon tip above the surface of the mercury. In viewing its action, one is vividly reminded of a mud-turtle taking a breath of air on a mill-pond. As others have expressed it, this apparatus actually breathes. Immediately upon the air being admitted the vacuum falls, its resistance increases, and the current through

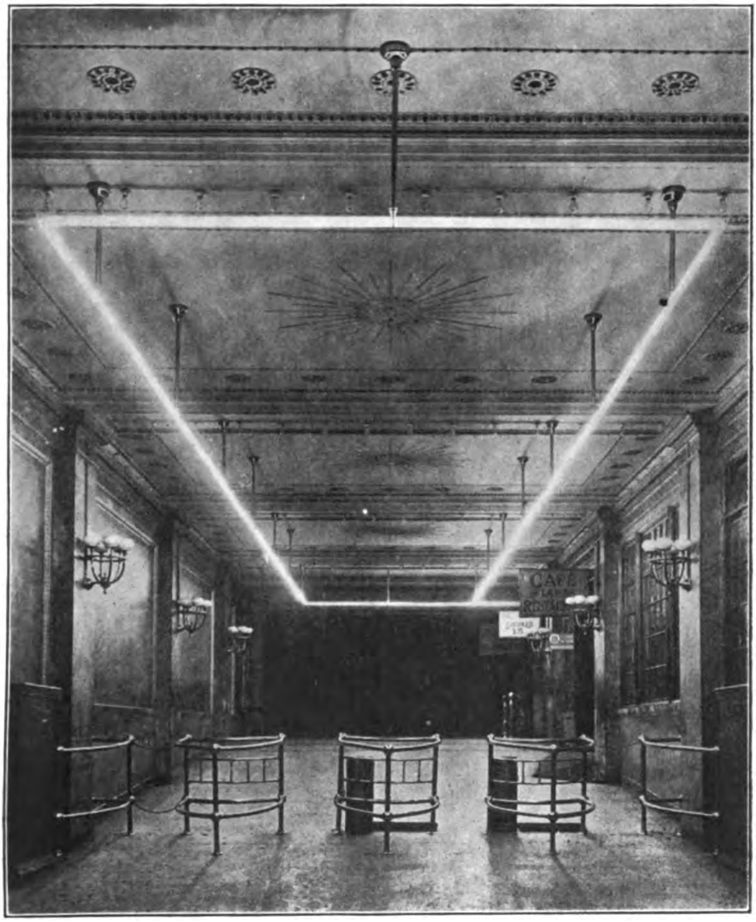


FIG. 7—Lobby of a theatre

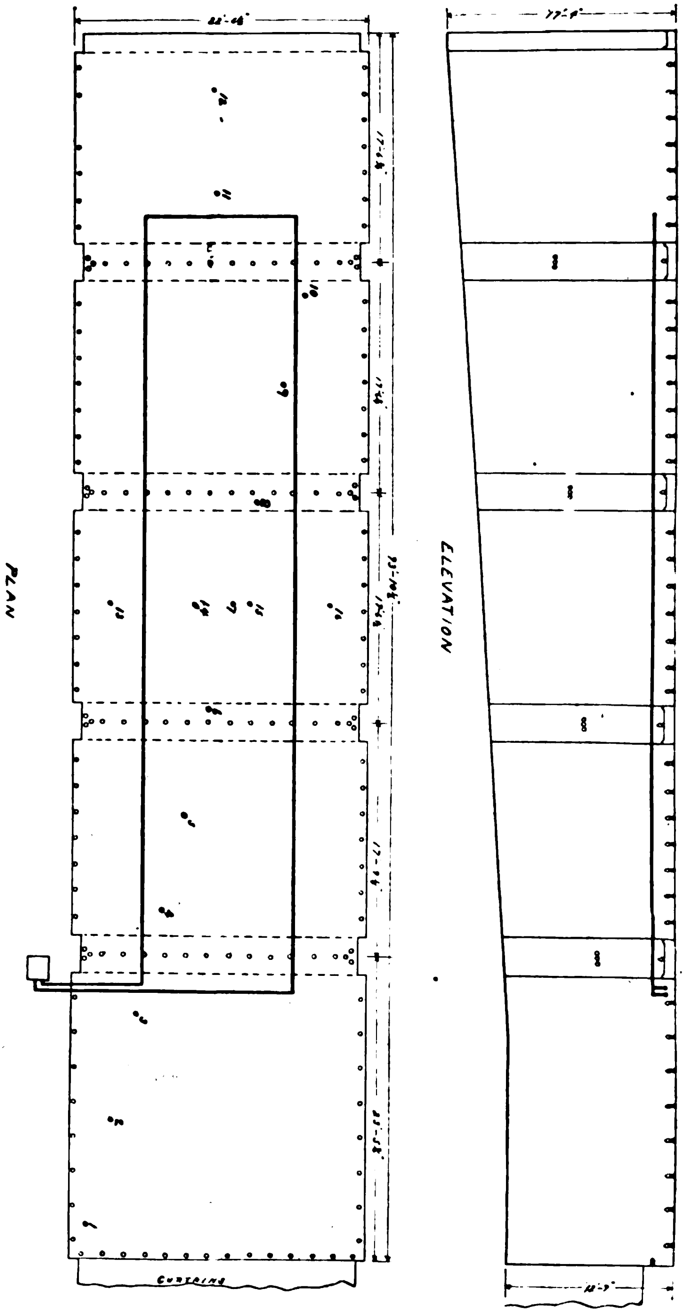


FIG. 8

it decreases as does also the current from the mains; therefore, the feeder magnet weakens and the displacer falls, thereby shutting off the air or gas inlet. This cycle is repeated about once a minute throughout the life of the tube, which is indefinitely long. Of course when the tube is not in service there is no leakage of air of other gas through the mercury covering the plug.

The following comparative illumination tests were made between the Moore tube located in the lobby of a large theatre (Fig. 7) and the incandescent lamps formerly used to light the same area

ILLUMINATION MEASUREMENTS IN HEFNER FEET IN THE LOBBY OF A THEATRE

Station	Moore Tube	Incandescent System
1	0.795	1.05
2	2.33	1.05
3	6.48	1.27
4	4.38	1.25
5	3.48	1.25
6	3.81	1.34
7	3.20	1.05
8	3.30	1.34
9	2.86	1.02
10	2.73	0.88
11	2.20	0.74
12	1.19	0.52
13	3.39	1.14
14	3.47	1.14
15	2.96	1.25
16	3.30	1.31
Mean illumination (average hefner-feet of 16 stations)	3.12	1.09
Average variation from mean	27%	16%
" volts	222 a.c.	115 d.c.
Amperes	21	51.75
Watts total	3075	5470
Power-factor	66	——
Area square feet	2110	2110
Watts per square feet	1.46	2.82
Illuminating efficiency $\frac{\text{Mean hefner-foot}}{\text{watts}}$	2.15	0.39

Therefore the tube system has 5.1 times the illuminating efficiency of the incandescent lamp system under the same local conditions. The useful illumination has been increased 450%, yet the current consumption is reduced 45%.

Although there are many factors which it is necessary not to lose sight of in determining the true value of any form of illuminant, nevertheless the sine qua non is the matter of efficiency. Does this apparatus produce more light for a given expenditure of energy than the other forms of illuminants with which it must naturally compete, is a question of vital importance?

A new and excellent type of portable illuminometer recently developed by Mr. Marshall was used to make these illumination measurements. At all stations it was placed 32 in. from the floor, although the floor of the lobby slopes towards the entrance end.

Fig. 8 shows a plan and elevation of this lobby. The tube is not provided with a reflector of any kind and therefore the ceiling was much brighter than when the incandescent lamps were used, most of which were located directly on the ceiling. The walls and ceiling are covered with a buff-colored paint. The tube operated directly from the street mains, 220 volts, 60 cycles, single phase.

If this tube had been longer its efficiency would have been still better, and by equipping it with a simple white reflecting enamel on the exterior of its upper half it would have had the benefit of a reflecting surface like most other forms of light in normal operation. Measurements of tubes so equipped show an efficiency corresponding to less than one watt per hefner and therefore approaching the theoretical limit for a light of such a commercially good spectrum.

The entire basement floor of a department store, which is solely lighted by four tubes each about 200 feet in length, is shown in Fig. 9. This basement was formerly lighted with enclosed alternating-current, 6-ampere, 60-cycle arc lamps. The goods are generally displayed on tables and shelves on the side walls, and the plane of measurement was chosen at the average height of the tables; that is, 36 in. from the floor.

The ceiling is 10 ft., 3 in. high and coated with gray paint. The tube is 199 ft. long, operating directly from the 60-cycle street mains; that is, there are no auxiliary devices to be taken into account as with some other forms of light. The center of the tube is 8 ft., 9 in. above the floor and the center of the arc lamp 8 ft., 6 in. above the floor. It was noted that various articles are suspended from the ceiling in this department, and that with the tube light the ceilings and walls were well illuminated, while with the arc lamps, due to their reflecting shades, the ceilings and walls were very dark.

The following comparative illumination tests were made between tube " B " when fed with pure nitrogen and therefore giving a yellow light, and the nine arc lamps provided with 15-in. white opalescent reflector shades formerly used to illuminate the same area.

ILLUMINATION MEASUREMENTS UNDER TUBE "B," DEPARTMENT STORE

Station	Moore Tube	Arc Lamp System
Vert. 1	2.84	1.30
2	1.76	1.14
3	4.66	1.25
4	2.02	0.68
5	2.84	0.59
6	3.75	0.75
7	1.34	0.45
8	1.91	0.68
Vert. 9	1.09	0.79
10	4.30	3.30
11	2.24	2.80
12	1.71	1.06
13	2.64	1.72
14	2.16	1.31
15	3.73	1.08
16	2.14	1.33
17	2.02	0.45
18	2.24	1.02
19	2.24	1.42
20	1.82	0.73
21	2.56	0.82
22	5.05	0.79
Mean illumination (average hefner-feet of 22 stations)	2.6	1.16
Average variation from mean	31.8%	40.4%
" volts	230	122
Amperes	24	53.1
Watts total	3500	4500
Power-factor	62.5%	70
Area square feet	3753	3753
Watts per square feet	0.93	1.2
Illuminating efficiency $\frac{\text{Mean hefner-foot x area}}{\text{watts}}$	2.79	0.967

Therefore the tube system with yellow light has 2.9 times the illuminating efficiency of the enclosed arc-lamp system under the same local conditions.

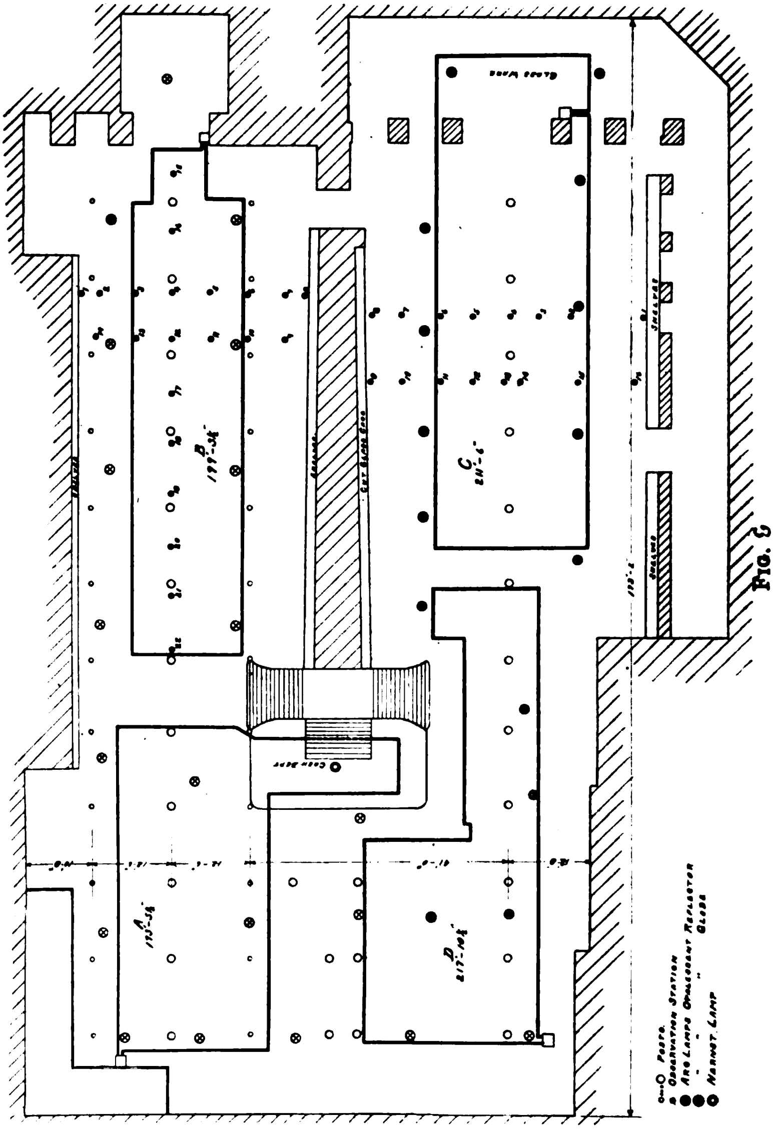


FIG. 3

The efficiency of this tube in terms of watts per hefner instead of watts per hefner-foot was determined by direct photometric measurement instead of by illuminometer measurements.

An accurately constructed photometer placed upon this tube showed it to be operating at 12 hefners per foot, which is equivalent to 2388 total hefners and an efficiency of 14 watts per hefner power from the street mains. This figure is obtained by simply dividing the total watts delivered to the tube from the city service mains by the total number of hefners. This bunsen photometer consists of a black wooden box 5 in. square and exactly 3 ft. between light sources. The tube passes through one end of this box transversely while at the other end is located a certified standard Reichsanstalt hefner-von altneck amyl acetate lamp. If the losses of the terminal box are deducted, the actual efficiency of this tube, simply as a light source—which is the manner in which practically all other light sources are usually rated—reaches the remarkably high figure of 1.3 watts per hefner. When a Moore tube is diffusing its yellow light, one seems at least to be able to see far better than when it is producing the same hefner power of white light.

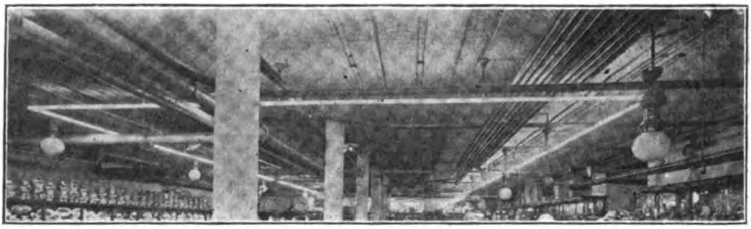


FIG. 10—Basement of department store

The useful illumination has been increased 220%, yet the current consumption reduced 22%; this amounts to a saving of 10c. per kilowatt-hour. At 65 hours per week this means $338.00 per year on this one tube. On the four tubes for the entire basement it means a saving of $1350.00 per year.

On account of the remarkable color qualities of the white Moore light, a request was made to change two of these yellow tubes over the china department to a white color, and the following comparative illumination tests were made between tube "C," 211 ft. long, when fed with pure carbon dioxide gas, and therefore giving a white light, and the ten 6-ampere, 60-cycle arc lamps provided with 12 in. spherical opalescent globes.

Fig. 10 is a photograph of this department taken solely by the light of the tube.

ILLUMINATION MEASUREMENTS UNDER "C," TUBE BAMBERGER BASEMENT

Station	Moore Tube	Arc Lamp System
1	0.91	0.34
2	1.71	1.73
3	0.89	0.36
4	0.75	0.40
5	1.06	0.63
6	2.18	1.51
7	1.31	0.97
8	0.47	0.45
9	0.49	0.29
10	1.11	0.51
11	1.96	0.54
12	0.88	0.57
13	0.66	0.23
14	0.63	0.32
15	1.71	1.11
16	1.25	0.43
Mean illumination (average hefner-feet of 16 stations)	1.12	0.65
Average variation from mean	37.5%	51.7%
" volts	227	122
Amperes	42	59
Watts total	5750	5000
Power-factor	61%	70%
Area square feet	4275	4275
Watts per square feet	1.34	1.17
Illuminating efficiency $\frac{\text{Mean hefner-fooot x area}}{\text{watts}}$	0.83	0.55

Therefore the white tube is 1.5 times more efficient than the enclosed arcs.

The delicately colored china ware is now exhibited under exact daylight conditions, and the general illumination is a marked improvement over that furnished by the arc lamps. The fact should be emphasized that the arc lamps hung much lower than the tube and produced a bad effect. The arc proper of the arc lamps was 28% nearer the plane of measurement than the tube. With the tube there located it would also show an economy over the arc lamps of about 78%.

Although the above tests indicate that this system is now the most efficient light source known, nevertheless not only theory but experiments already made show that greater advances in efficiency are yet to be made. The best gaseous-conductors particularly adapted for selective radiation must be determined upon. For example, nitrogen has about twenty times the efficiency of hydrogen. A gaseous-conductor must also be selected that not only has proper color values but must maintain high efficiency over wide ranges of intensity; for example, mercury vapor (to say nothing of its color) is very inefficient in the long-tube system. It is only efficient at intensities which should be considered too high, and which is also the reason why the mercury tube is so sensitive to temperature changes.

Moore tubes are now used in lengths varying from 40 to 220 feet. The following curves show the watts per hefner for 40 feet to be 2.5, and for 220 feet to be 1.4, on the basis of a yellow light. Therefore when tubes are operating at 12 hefners per foot, which is the average intensity now used, tubes from:

40	to	70	feet	use	a 2-kw.	transformer.
80	"	125	"	"	a 2.75-kw.	"
130	"	180	"	"	a 3.5 "	"
190	"	220	"	"	a 4.5 "	"

In order to insure steady light, the power-factors of the circuits supplying these transformers average at present 65%. This is obtained either by using a shell-type transformer of special design with a leakage reactance of about 65%, depending on the size of the transformer required, or there can be used a standard type of core transformer, operated in series with a special type of adjustable inductance consisting of two composing coils on the center leg of an iron core of the shell-type formation.

Feeder-valve solenoids of four sizes have been found sufficient, and are usually connected in series with the low-tension circuit of the transformer and inductance, although they are sometimes operated by the high-tension circuit.

Although the average power-factor is now about 65%, there is no theoretical reason why all these tubes should not operate at a considerably higher power-factor. In fact a very recent improvement in the valve which has entirely eliminated capillary attraction, has made it practical to adjust tubes to a power-factor as high as 84%—which is a decided improvement over some of the first tests published, and makes the tube far better than either the alternating-current motor or the arc lamp in these respects. Since all of the electrical factors of the entire system are based on the conductivity of the gas column, it is possible to vary the power-factor over a wide range simply by changing the degree of vacuum by regulating the amount of gas fed to the tube.

The following curves show the relations exiting between the salient factors that have to do with the tube performances.

Curve *A* shows how the amperes of the low-tension side of the transformer at 220 volts vary with the length of the tube.

Curve *B* indicates that the actual voltage on the tube terminals for 40 feet is 3146, and for 220 feet 12,441 at 12 hefners per foot.

Curve *C*. Since the no-load transformer losses and also electrode losses become a larger percentage of the total watts as the tubes are shorter, therefore the watts per hefner grow less: that is, the longer the tube the better the efficiency.

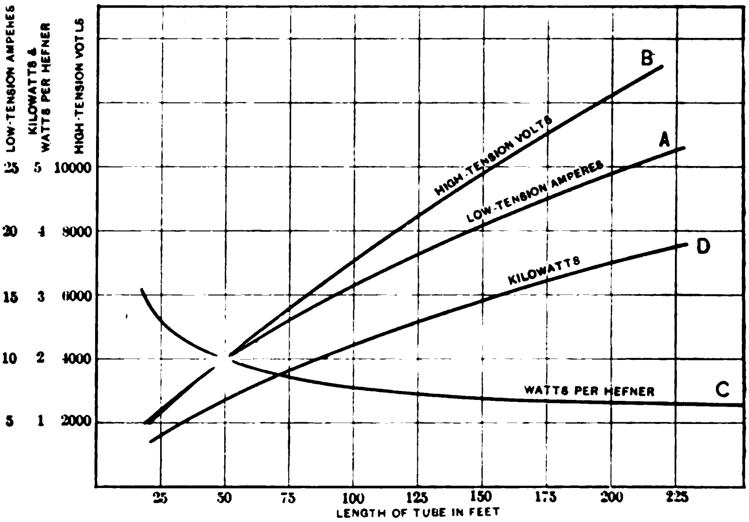


FIG. 11

Curve *D*. Doubling the length of a tube does not double the kilowatts required.

Curve *E*. These tubes soon become seasoned; that is, use up all foreign gases, and then their intensity remains perfectly constant for an indefinitely long period of time.

Curve *F*. The efficiency also remains constant.

Curve *G*. The efficiency does not vary over a wide range of supply voltage.

Curve *H*. The light intensity is directly proportional to the voltage, not as the square or the cube of the voltage as is the case with incandescent lamps. This is an advantage of great practical importance.

Curve *I*. The light intensity is nearly proportional to the watts.

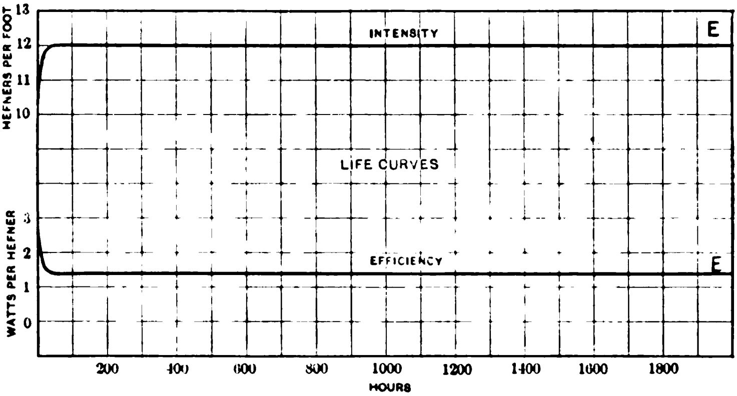


Fig. 12

Curve *J*. The light intensity is proportional to the tube amperes, and that a tube radiating 13 hefners per foot of yellow light requires three tenths of one ampere.

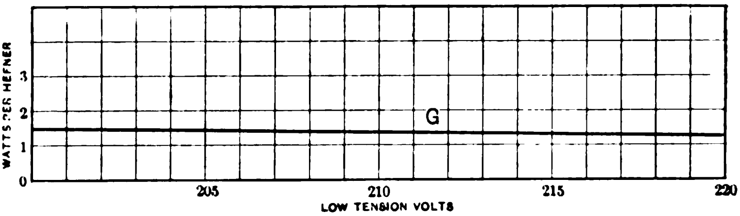


Fig. 13

The degree of vacuum required in these tubes is about 0.10 of a millimeter which, comparatively speaking, can be called a high vacuum. This vacuum is maintained within 0.01 of a millimeter of 0.00001% of an atmosphere either above or below the normal degree of vacuum. The solution of this very difficult problem of maintaining a degree of vacuum so nearly constant, was found by taking advantage of the fact that but slight changes in the vacuum cause enormous changes in the electrical resistance of the gaseous-conductor. For example, a tube 220 feet long at its lowest vacuum (0.11mm), takes 24 amperes, but at the end of every minute this has crept up to 25 amperes, when a new supply of gas causes the amperes slowly to drop again to 24. Of course it is impossible to detect this slight oscillation either in the steadiness or intensity of the light in the tube. Making use of electricity to govern the vacuum is equivalent to using a multiplier of about 400,000.

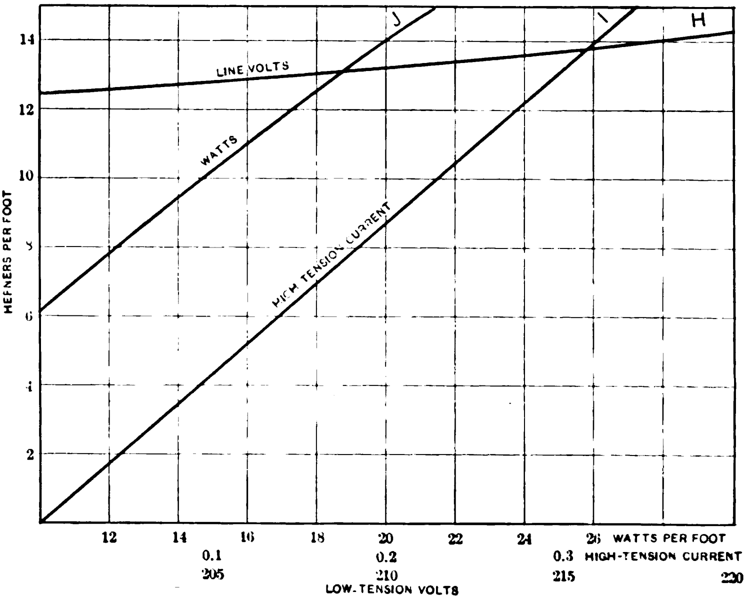


FIG. 14

These long tubes are built in place by hermetically sealing together 8 ft. 6 in. lengths of 1.75 in. glass tubing, with walls $\frac{1}{16}$ in. thick, by means of a new blast illuminating gas—fire or double-flamed torch. This work can be done rapidly and cheaply since in a 100-ft. tube about a dozen joints are needed and only about two minutes are required for each one. This has necessitated the development of a new trade: namely, "glass plumbing."

The two ends of the tube within the terminal box each contain a graphite cup electrode 8 in. long. Immediately in front of one of these electrodes a branched small-bore tube extends to the bottom of the feed valve, see Fig. 3, and the other branch is available to be connected temporarily by a rubber hose to a new small portable oil vacuum-pump. The electricity is turned into the tube shortly after the pump is started and the amount of light resulting indicates in a measure the degree of vacuum in the tube. But in investigating a field of this nature a simple, rapid, and accurate vacuum-gauge was found to be very necessary, and it has proved to be as valuable an instrument as a compass is to a mariner. It can be calibrated to measure to one ten-millionth of an atmosphere.

As soon as the vacuum of the tube is sufficiently high, the feed-coil is adjusted to feed at proper intervals the right quantity of air or other gas. When the light automatically and continuously feeds itself from the atmosphere, the supply of which is of course inexhaustible, its life can be said to be indefinitely long. When it is desired to feed the tube on nitrogen only, the air is simply made first to pass through a small iron cylinder containing enough phosphorus to last several years. Should a longer life than this without any attention be desired, several cylinders can be used in series and these can be renewed an indefinite number of times at a negligible cost. Effectually to prevent more than is necessary of the atmosphere from coming into contact with the phosphorus, or being continuously in contact with it when the tube is not in use, it has first to pass through a small mercury trap.

To feed the tube CO_2, a bottle containing a piece of marble and a little hydrochloric acid automatically generates this gas only when the tube requires feeding. Therefore this small gas generator needs only a new piece of marble at the end of several years.

Various portable or unit forms of this light have been designed. For example, the one shown in Fig. 15 resembles somewhat an arc lamp. It operates at 220 volts and requires 25% less watts yet gives 25% more useful illumination than an enclosed arc.

The automatic feeding-valve is of course applicable not only to alternating-current vacuum tubes but also to direct-current vacuum tubes. It can be made invaluable for all kinds of vacuum-tube apparatus, such as X-ray tubes, vacuum oscillographs, wireless telegraphy or telephony, transmitters and receivers, vacuum or vapor rectifiers, or lamps.

A careful analysis of this system of illumination in general, discloses the large number of advantageous features it possesses. It is the first artificial light that can rightly be called imitation daylight. Natural daylight is the only ideal light that can ever exist and the eye accords with it, therefore the nearer any light source approaches it the better, and vice versa The absence of the red rays in daylight, for example, would far from improve it. This system is so much nearer natural light imitation that it is in a class by itself. But these tubes furnish a perfect diffusion of light because the light radiates from such extremely large areas as compared with all the old style spots of light, and therefore if desired a more nearly shadowless light can be produced than any other known means.

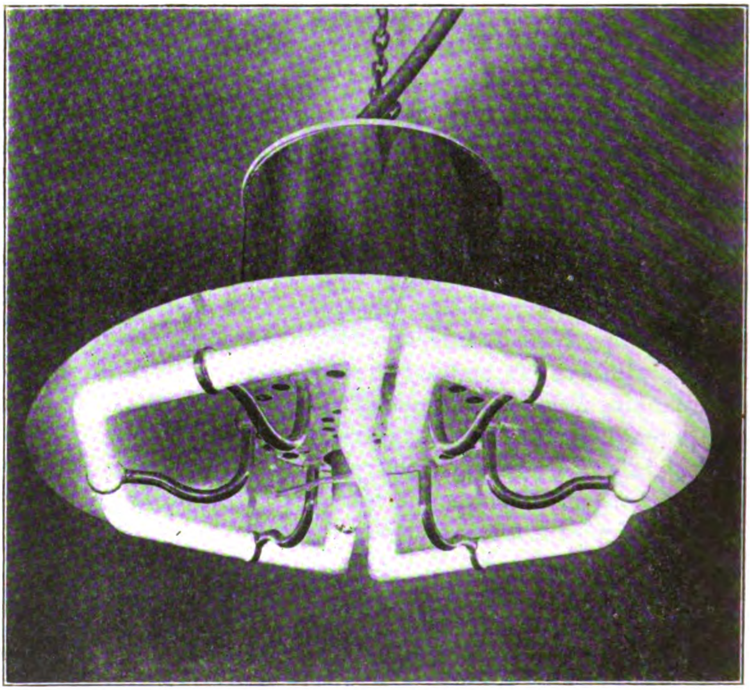


FIG. 15—A small Moore light unit

The recently appearing types of incandescent lamps having improved efficiencies, such as the osmium, tantalum, zircon, graphitized carbon, tungsten, osmin, osram, titanium, and helion lamps are all obtained by causing solids to get overheated due to electricity passing through them. These new lamps—all based on an old principle—are only of transient interest, an interest of a vastly lower order than the interest that should attach to obtaining illumination by electricity passing through, not solids, but gases. They will not bring about a permanent radical change in the lighting situation. But such a change is now gradually being brought about by the vacuum-tube. However, by this it is not meant or claimed that all other forms of light will be abandoned. The candle business is larger to-day than ever before, and history shows that the electric lamp has interfered very little with gas. But changes must come. Each form of light has its own particular sphere of usefulness, which varies in size in accordance with its intrinsic worth and age. Some are just starting on their campaigns of usefulness, and others have reached their prime. Light resulting from gaseous conduction, it can truly be said, is right both theoretically and practically and therefore will probably survive for centuries.

It is simply claimed that this new system of electric lighting gives the up-to-date illuminating engineer one more available method for solving some of his problems and that some of its fields, as is the case with all other lights, are exclusively its own.

It should be remembered that the enclosed arc rapidly displaced the open arc, due to better diffusion and lower maintenance cost, notwithstanding a 50% loss in efficiency, but this new system in turn excels the enclosed arc in all of these factors.

The recent high efficiencies that have been obtained by other forms of illuminants have always been gained at the loss of some other salient factor; for example, such as life or color, but not so with this tube light. It is based throughout on thoroughly well known engineering principles that are properly applied. "The proof of the pudding is in the eating thereof," and the proof of every electric light is the illumination thereof. The term spherical candle power manifestly cannot apply any more logically to a long tube than can the law of inverse squares be properly applied to its light emenation. It is an indication of broadmindedness to have a complete indifference for all new forms of lights that have even a higher intrinsic brilliancy than the older forms with which we have long been familiar.

In this connection it is well to notice that many of these new forms of spot lights have enormous intrinsic brilliancies, because it is impossible to make them in lower candle powers.- Besides the disadvantages of the high candle powers of these new point light sources, mechanical difficulties may make the ordinary used voltages impracticable. Few persons realize how comparatively little need there really is for small units of light, such as were contrived and used by our forefathers.

Abundant light is becoming more and more of a necessity and less of a luxury every day. There will always remain a small field for localized light sources, but so long as any new form of light is in the form of a spot; that is, so long as it is a highly concentrated light source, it is not worthy of much serious consideration so far as the great bulk of the lighting that is now needed by commerce is concerned. Large areas represent at least 80% of the lighting business. They should be illuminated by diffused light, therefore the only proper procedure is directly to generate a diffused form of light; that is, use a large and cool vacuum-tube, not a very small and a very hot filament and then try to scatter or soften its light and thereby waste about 50% of it, either by a diffusing globe or a reflector of some kind, to avoid glare. The long-tube system has the necessary natural characteristics that make such devices superfluous. Its enormously greater area is responsible for its correspondingly low intrinsic brilliancy.

Since it is possible and practicable to use these tubes graduated from an intensity of light per foot that is almost negligible up to 30 or more hefners per foot, it is impossible to state arbitrarily just what is the intrinsic brilliancy of a Moore tube. The average long tube now in use operates at 12 hefners per foot. The following table compares the tube with some other illuminants on the basis of hefners per square inch.

Moore light	at 6 hefners per foot	0.33
	at 12 hefners per foot	0.66
	at 36 hefners per foot	2.
Cooper Hewitt mercury tube		19.
Incandescent filaments		250.
Nernst glower		600.
Arc crater		10,000.

Some authorities have stated that an intensity greater than about 5 hefners per square inch is beyond the theoretically correct limits, therefore this light is the only one that has a low enough brilliancy not to fatigue the eye. This has also been demonstrated by practice. It is remarkable that an intrinsic brilliancy as low as 0.33 per square inch is commercially thoroughly practical. Fig. 16 shows a tube that has been operating at this low intensity for over two years. It was also the first tube to be operated on alternating current from street mains. Even at this low intensity, the store is far more brilliantly and satisfactorily lighted than with the 16 c-p. incandescent lamps hanging low on flexible cords which were formerly used. So far as primary brilliancy is concerned, the tube far excels all other electric lights—all of which certainly need to be amply equipped with diffusing shades, etc.

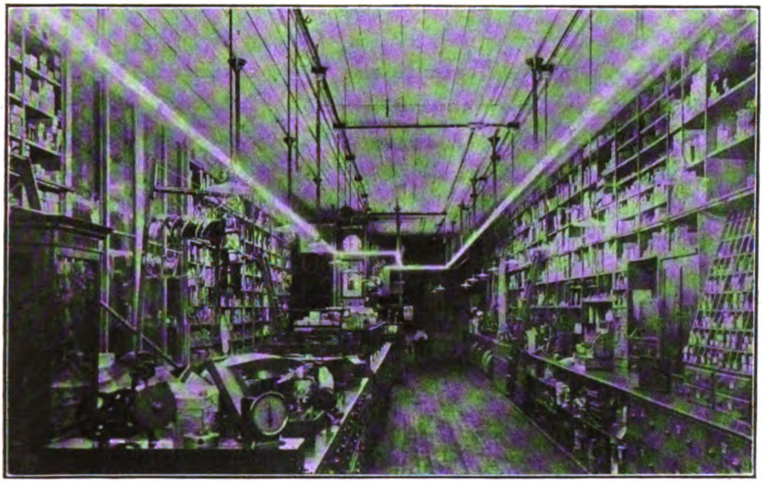


FIG. 16—Interior of hardware store

That great progress has been made in tube lighting is clearly proved by calling attention to the fact that the tubes in the "Moore Chapel" at the Madison Square Garden Electrical Show of 1898 operated at only ¼ of a hefner per foot while now a hundred times this intensity is easily reached.

Posterity will probably comment on the boast of one of our greatest illuminating companies, that it had to screen every light source in its model new building. Vacuum-tube illumination will obviate the necessity of a law prohibiting all kinds of glaring lights.

Illuminating engineers should not lose too much time by giving undue attention simply to the utilization of light, but should also rapidly come to a realization of the prime importance of the best methods of producing artificial light.

The Moore light is generated in such a manner that it needs no unsightly and expensive auxiliary apparatus either to distribute it by reflection, or to diffuse and soften it. It should be borne in mind that illumination from gaseous-conductors is a comparative infant in the commercial world. There is a marked difference between the illumination produced by a Moore tube and intense-point sources. This very marked contrast is shown best by suddenly throwing off the tube light and immediately throwing on incandescent lamps—especially if there are many of them and bare, and suspended by flexible cords.

After becoming accustomed to the tube light, workmen, whether machinists or employees in packing and shipping departments; very much appreciate the fact that they "can't get into their own shadows." For reading addresses or markings on loading or shipping platforms it can scarcely be surpassed.

This tube lighting accurately resembles cove or concealed lighting, yet there is no necessity for concealing the tube; should it be desired to conceal the source of light the cove itself is not needed, because all that is necessary is to place an opaque reflector on the lower side of the tube so that all of its light would be thrown toward the ceiling and illuminate the room therefore entirely by reflected light.

Incandescent lamps were originally placed behind coves because of their objectionable high intrinsic brilliancy, and the tendency is to allow the sins of the incandescent lamp to be visited upon the tube. The only reasonable excuse for placing a tube behind a cove is that the light source is concealed; but even this reason is not logical, because the intensity of the tube can be adjusted to be but little brighter than the ceiling is as a reflecting surface. Take for example the tube now lighting this hall. It is in front of the cove or cornice, not concealed in any way, yet its simplicity prevents it from being obtrusive. It harmonizes with its architectural surroundings and its height places it entirely out of the direct line of vision. Even though it be deliberately stared at, it does not dazzle the eye in the least nor distract one's attention as does the dim and streaked ceiling when the incandescent lamps are used. The most common kind of natural light is almost shadowless and always pleasing, as is also the lighting of many large areas by means of skylights, and so are artificial imitations of diffused daylight if made intense enough. A lack of uniformity in intensity does not rest the eye.

All authorities insist upon the avoidance of bright spots. This is accomplished by other systems at an enormous sacrifice in efficiency. Take for example the really beautiful lighting of many auditoriums using light diffused through glass ceilings. However, from the four standpoints of efficiency, simplicity, safety, and first cost, a little thought would convince the most skeptical of the enormous advantages, both in theoretical conception and practical application, of simple exposed glass tubes which would accomplish the result sought after equally well, yet at an enormous saving in operating expense.

It is the blinding brilliancy of the mercury tube that makes even a direct glance at it so very harmful to the eye. It is true the mercury tube is a light-source of larger area than all point sources, but a careful analysis will clearly show that in this respect it is but a short step in the right direction, and that its area for a given quantity of illumination will have to be multiplied a score or more times, as it is in the Moore light, in order to obtain an intrinsic brilliancy low enough to meet conditions both theoretically and practically correct.

A study of the history of the development of all light sources shows the vacuum-tube to be a logical conclusion of the progress of evolution. All portions of a long Moore tube are uniformly luminous. It has a governable intensity from zero to dazzling brightness; therefore any theoretical specifications can be met in practice by resorting, for improved methods of illumination, to the gaseous-conductor, not to a solid one. Carefully tracing the evolution of all forms of light from remote ages down to the present time as regards the following seven most important factors: diffusiveness, color, steadiness, absence of heat, efficiency, safety and first cost, all—clearly prove this long tube system to be a natural sequence and that the times are now ripe for it.

Widely spaced 50- and 100-c.p. lamps were commonly used twenty years ago, but custom and necessity gradually changed them to 8- and 4-c.p. lamps. Next they were placed close together in rows and then laid horizontally (as they are behind the coves of this room) clearly pointing to their natural successor in the direct line of progress; namely, the tube.

The arc lamp has changed from, first, the unsteady short open arc, to the much longer enclosed arc which multiplied the area of the light source many hundred times, to the enormous "diffusers" now used to improve as much as possible what I believe to be the fundamentally wrong principles of arc lamps and incandescent lamp clusters. The flaming arcs go one step further both in lengthening the arc proper and increasing the apparent light source to the entire area of a large globe. The Moore tube virtually consists of an "arc" drawn out to a length of several hundred feet.

Steadiness is a factor of vital importance to any form of light, and in this respect the long tube is excelled by none. Of course it does not flicker like an arc lamp and is much less affected by voltage variations than all forms of heated solid conductor lamps.

Stroboscopic tests of the light of the tube reveal an image better than that obtained from enclosed arc lamps, notwithstanding the fact that the heat-constant of the tube as the current wave passes through zero is less than that of any other form of light. Therefore when the supply switch is opened the tube light "goes out" quicker than all other lights, a fact which should be valuable for signalling but which also in a measure explains the high efficiency of the tube. Tubes of this nature will operate successfully on all frequencies, but at frequencies as low as 25 cycles the images will probably become too pronounced unless two- or three-phase currents are available, in which case by the use of multiple tubes the images of moving objects are entirely removed. The highest frequency in use at present for operating these tubes is 480 cycles, and is furnished by a motor-generator on 220 volts direct current. Careful tests on various frequencies up to about 10,000 cycles have shown that the number of alternations of the current used to excite these long tubes has nothing to do with their efficiency.

The only commercial and proper method of comparing all sources of light is on the basis of their ability to produce useful illumination, and not by any other basis. I have advocated for some years past the comparing of all lights by measurements of illumination and not by candle powers, and now see indications of this procedure becoming standard. The term hefner-foot will soon replace the unsatisfactory candle power, and contracts for lighting any area will be based on specifications calling for a definite intensity in hefner-feet on each square foot or square yard of the area to be lighted. This is far more practical than agreeing to furnish a lamp which is supposed to require no more than a certain number of watts per candle power, at the beginning of its life. All light users want to deal with terms that have to do with useful light, and this is one reason why the term " watts per candle power " has always been so extremely unsatisfactory. There should be used a single commercial quantity or figure that would correctly express the " illuminating efficiency " of each and any system of lighting used to illuminate a given area. If the area, and, therefore. all of its accompanying reflecting surfaces be changed, the relative values of this figure for each system is also liable to change, because some systems (for example arc lamps) are more benefitted, comparatively speaking, than are others by certain reflecting surfaces and other local conditions. Such a figure or value is readily obtained by dividing the average of the hefner feet measured at a suitable number of stations by the watts per square foot. This method will finally be widely adopted not only by illuminating engineers but also by the intelligent public—now that simple and perfectly self-contained illuminometers are available. The term hefner-foot is preferred because the hefner is the only practical primary standard. There is no longer any excuse for using the term candle power, and it should rapidly be dropped. The foot is still the commercial unit of length in this country.

If incandescent lamps were generally used as individual light sources, then watts per candle power would be the salient term, but since the vast majority of incandescent lamps are not used individually but simply as inconspicuous parts of a system of illumination, then the average hefner-foot becomes the factor of prime importance: that is, the illuminating efficiency, not the efficiency of an illuminant. We should be a little concerned about the specific efficiency of the lamps behind the cove in this hall, but very much interested in the ability (that is the efficiency, of the incandescent system as a whole to produce the result sought after: that is, to illuminate uniformly and without glare every square foot of this floor with a minimum expenditure of energy. Watts per hefner-foot is the important factor, not watts per hefner.

I believe that the proper way to compare all forms of illuminants would be approximately on the following basis:

1. The area to be lighted should be about 40 by 80 feet, and of approximately the shape indicated by these dimensions.

2. The illuminants must not extend below a horizontal plane 10 ft. above the floor.

3. The award is to be made entirely upon the results of illuminometer tests in a plane 30 in. above the floor and the stations of which are to be located as follows: ten equal spaces on the center line of the longer dimension, ten equal spaces on the center line of the shorter dimension, and ten equal spaces on the diagonal. The average of these thirty readings is to be divided by the total number of kilowatts used from the street mains by each form of illuminant, and the highest quotient (light units per energy unit) will determine the placing of the award.

It is not surprising that the tube should surpass the incandescent lamp both in efficiency and diffusion in the lighting of an area of this size, because the incandescent lamp is wrong theoretically—too far away from natural light—it is too small, too red, too hot. The highest temperature at which glower lamps operate would make them do better, about half as well as the tubes. So with all the incandescent types of lamps, to say nothing of the bother and expense of replacing them, either in whole or in part. Arc lamps would be out of the race, because of inefficiency, glare, flickering, wide variations in candle power between feedings, poorly distributed light, noise, dirt, etc., besides the maintenance expense of recarboning and cleaning. Compare the simplicity of the method of obtaining diffused light by means of the tube with the really commendable attempt to obtain a comparable diffusion by equipping arc lamps with concentric diffusers that are as enormous as they are crude so far as the means to the end is concerned. Especially is this the case where light balancing selector diffuser ceilings are installed. They very pointedly indicate the need of a tube light.

During the first year of its use—1903—the gaseous-conductor of the Moore tube was produced by chemical means, which has been comparatively recently superseded by the automagnetic valve. Therefore the lapse of time since the first automatically fed tubes were installed being so short, it is not now possible to state definitely what their final life will be, beyond the general statement that some of these tubes have already been in operation over 4000 hours without change, and that there are good reasons for believing that they should continue to run at least again as long, which is a much longer life than any other form of illuminant yet invented. This whole system is one with an exceptionally large number of variables, and this also applies to its life, because it depends partly on the intensity at which the tube is operated and the particular gas used. Since air or other gas is regularly admitted to the tube and changed to some solid form, due to certain electrochemical reactions, it is certain that the time of operation without any attention whatever cannot be prolonged indefinitely. Before adopting the chemical method of obtaining a nitrogen supply for the long tubes, it was stored under about three pounds pressure in a small tin cylinder placed in the terminal box, which supplied an average tube before needing to be recharged for considerably over a year. Therefore the quantity of gas (nitrogen for example) necessary to support a light of 12 hefners per foot is so small that a tube of average length should remain in perfect condition for a number of years before it would be expedient to remove the small quantity of dark-colored powder which may have accumulated only within or near the graphite electrodes.

When a tube has been properly exhausted, the discoloration in front of the electrodes should not at any time extend more than two or three inches. When a tube is striated, it indicates that other gases are present that are foreign to the one decided upon to be used.

The light source of all other lights needs to be renewed, but in this case the light-giving tube itself will last an indefinitely long time, since it is neither consumed nor becomes blackened in the least. Should any renewal be required it is at the electrode which can be replaced comparatively cheaply.

The cost of a long-tube installation, due to its being construction work, varies with its location, its length, its shape, the intensity of the light required, the kind and number of fixtures desired, and other local conditions; but is already less than the cost of a first-class incandescent lighting system with its necessary wiring, fixtures, and shades. Eventually it will be far cheaper. It should be borne in mind that the first cost of this tube corresponds with the entire cost of an incandescent lighting system—its iron piping, wires, cut-outs, fixtures, shades, and lamps—and also that the first cost should be considered only in connection with the fact that in many instances this tube will pay for itself several times over during its first year of use from the amount saved on what the current bills would have been if incandescent lamps had been used to produce the same amount of useful light.

This system is extremely simple. Only two parts are essential: the light-giving tube and the terminal box. We are so thoroughly familiar with the ordinary incandescent lighting system that it is hard for us to realize that it has become really very complicated with its hundreds of different devices. Its most enthusiastic supporters a few years ago would have declared the present conduit system as entirely prohibitive, especially when concealed. But now almost all of it can be eliminated by simply installing a light-giving tube, even after the decorations have been completed, as was done in the last few days in this room.

Architects have long considered electric wiring problems one of their most vexatious burdens. Now a terminal-box can be used as a center of distribution from which there radiates a number of long tubes to illuminate portions of the same floor, or extend to floors above or below. A tube provided with a reflecting enamel on one side is a far simpler device for lighting show windows than the extremely cumbersome combinations of rows of incandescent lamps with mirrored reflectors in sheet metal troughs, etc. This tube system has no complicated mechanism like arc lamps, for example, but instead the only moving part is the displacer of the feeder valve which in its design is about as near being frictionless as is conceivable. Normally, its movement is less than 1/32 of an inch, and some of these valves have required no attention and yet have been in active use over 4000 hours. They should continue to operate an indefinitely long time.

As a scientific instrument this automatic valve is another combination of ruggedness with marvelous sensitiveness, in which respects it resembles a telephone receiver. The very nature of this system is such that the liability of a normal tube being broken is very slight; yet in case of accident a new piece of tubing can be quickly and cheaply inserted. The ideal and rapidly approaching final position of such a tube is against or almost against the ceiling, the illumination then most closely resembles light coming from the sky. But many users, notwithstanding the high efficiency of the tube light, desire to reduce their bills still further by using a less number of hefners per foot, and support the tube on long fixtures. When a tube is cracked or broken the inrush of air of course instantly extinguishes the light, but the electrical apparatus is in no way disturbed.

This is a hardy piece of apparatus, not a delicate mechanism like the incandescent lamp. Glass tubing properly supported is far stronger and more flexible than most people realize. The voltage on a tube's terminals can either be raised or lowered without harming in the least either its life or its efficiency. The conductivity and light of these tubes are practically unaffected by temperature changes, especially those emitting yellow light. Another installation which depicts a quality of this light peculiarly and exclusively its own is fifty feet of tubing skirting the bottom of a large aquarium. The fishes are not disturbed in any way by its presence; that is, neither by shocks nor by heat. Neither moisture nor fumes affects these tubes. There is no multiplicity of sockets and wires to become damaged or short circuited and the tube can be most easily cleaned.

The light-giving tube itself is harmless either to life or property. The terminal box is made of steel with a slate bottom so that even though the small transformer within it should completely break down, smoke only would result. It is impossible for the exterior of the terminal box to get hot enough to set fire to anything. It is carefully designed so far as ventilation is concerned, and is always mounted so that there is an air-space all around it. With this loop tube system, aside form the ordinary short feed circuit, there is no part of it to be classified as a "risk" since all of the purely electrical apparatus is securely contained in a fire-proof terminal-box.

Fig. 17 shows the terminal-box, but it also shows, inadvertently, though most strikingly, the contrast between the simplicity of the tube and the complexity of the network of wiring on the ceiling which it has supplanted.

Owing to the high efficiency of the tube and the large area from which any heat accompanying the light can radiate, the temperature of the tube is remarkably low, being in the neighborhood of 100° fahr., therefore it cannot injure either perishable goods or the health of those working under it. In basements for instance in summer time, the fact that only about one sixth as much heat is dissipated as would be if incandescent lamps were used is a matter of prime importance to the problems of ventilation, etc. It was of much scientific interest to note that tubes at the same degree of vacuum with the same amperage flowing produced a widely varying quantity of light as the kind of gaseous-conductor was varied and that the temperature of the tube was higher with the gases producing the most light.

This system, from a number of standpoints possesses great flexibility. This is illustrated, so far as the distribution of the tube is concerned, by Fig. 18, which shows the layout of tubes on the mezzanine floor of a public building office. These remarkably varied shapes and lengths are due to the necessity of light being located to suit each particular desk, table, set of files, etc. Since tubes can be made of any diameter and form, the artistic possibilities of electric lighting are multiplied many fold.

Flexibility is again demonstrated by the facts that the intensity and also the color of these tubes can be varied over wide ranges. The higher refinement of the art of illumination is bringing into view more and more prominently the color of all light sources. Not their individual colors, however, but the color values they give to surrounding objects, is fast becoming, next to efficiency, the most important fact in connection with any light. This light is the first and only illuminant the color of which can be changed at will over a wide range. This is accomplished by changing the character of the gas within the tube. If a tube is permitted to feed itself on plain air, an efficient

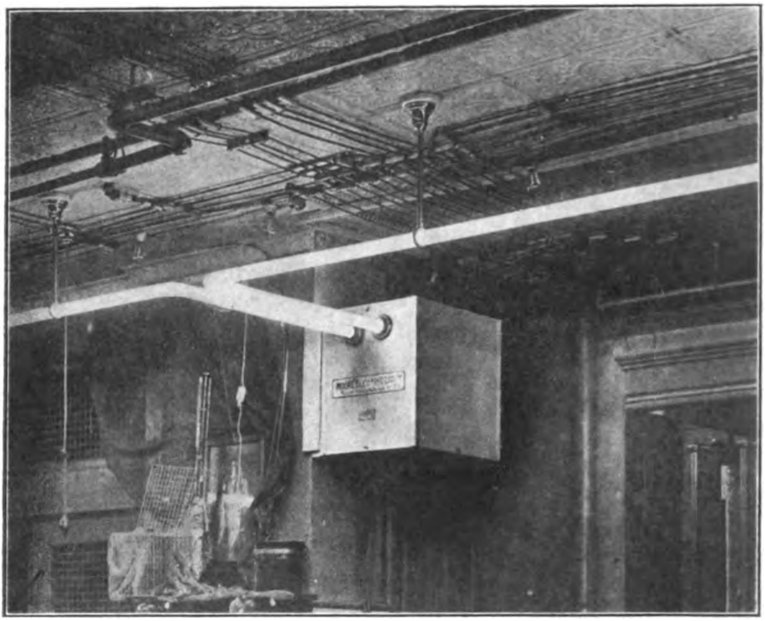


FIG. 17—Exterior of terminal-box

pink light results, but if the air is first caused to pass through a cylinder of phosphorus to absorb its oxygen a golden-yellow light is produced that is the most efficient light source known. When operated at higher intensities than 12 hefners per foot, and viewed in line with incandescent lamps, it is apparent that the colors are about the same as well as the color values of all objects viewed under it.

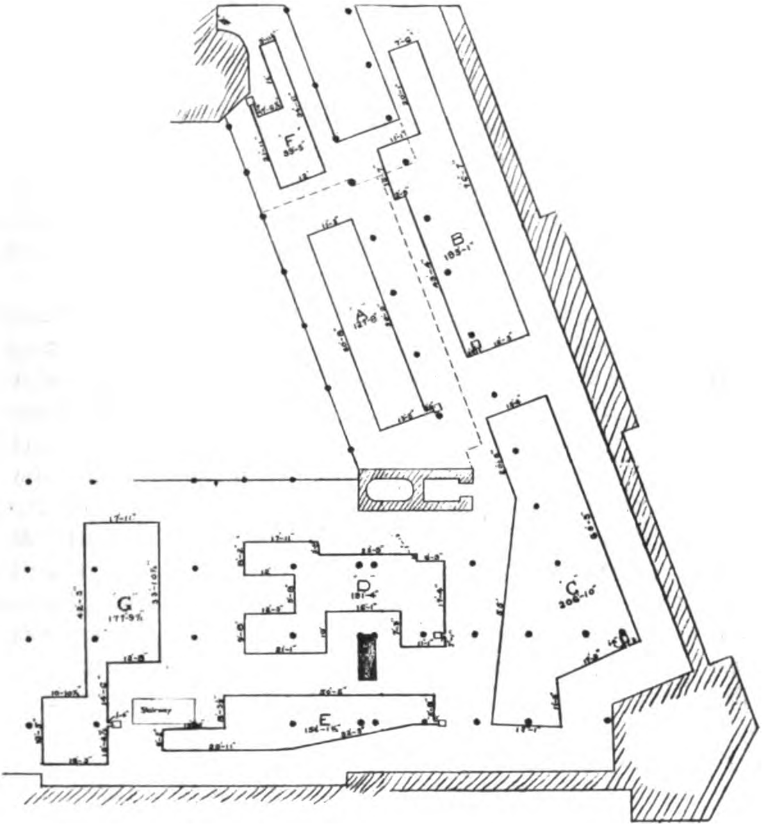


FIG. 18

Although our firm purpose should always be to imitate daylight, nevertheless its color values are not constant quantities at different hours of the day. Fortunately, the spectrum and color values resulting from the use of carbon dioxide gas as a gaseous-conductor in a clear glass tube should be decided upon by scientific societies as accurately representing average diffused daylight, not direct sunlight. It will finally be recognized as the only standard of light. Specifications can be drawn and adopted which will enable the accurate reproduction of such a standard at will. Already all of our present so-called primary standards are acknowledged as being too red, but such a vacuum tube as a standard will have a color value which will remain perfectly satisfactory so long as daylight lasts. Further than this these specifications can be made to determine with great accuracy a definite intensity. We thus have a primary standard as regards both color and intensity.

When these tubes are supplied with CO_2 they appear pure white. Most inexperienced persons, especially when contrasting the tube light with reddish lights, criticize the color as being too blue without realizing that daylight is a decidedly bluish-white. The laws of nature make the operating expenses of the pure white light tube almost double that of the yellow-light tubes, because the eye is effected to a maximum degree by yellow rays, But the white tubes which simply contain CO_2 have been used for over a year by stores in their ribbon departments for matching colors, day and night, because its spectrum remains absolutely constant. There are many other industries where color values are of vital importance. Also, since the color factor is now under perfect control, those light rays can be scientifically selected which are essential for the forcing of all kinds of plant life, flowers, fruits, and vegetables. The color of the light can be varied by feeding the tube any gas as each has its own spectrum, or by using multiple valves, etc., mix various gases within the lighting tube itself. White tubes are daily being put to most vigorous tests at the works of one of the largest silk dyeing establishments in this country, but no difference can be detected in the most delicate shades when matched either under the tube or in average natural daylight. For some time past artists have been mixing their colors at night under the white tubes. Portrait photographs are also being made under it that equal those of natural light. Since the yellow tube light is about the same as that of the incandescent lamp it is being used successfully by clothing merchants and florists. Also on account of its uniformity of intensity it has proved its superiority for photographic printing.

It is interesting to note how different the same tubes lighting an ordinary store window appear in the afternoon when the sun is shining and after seven o'clock at night. The tubes that are yellowish white at night time appear orange colored during the day, and the tubes that are a pure and dense white at night appear a pale blue during that day—in fact if exposed to brilliant daylight no light can be seen in them at all.

Users can obtain the exact quantity of illumination desired on a given area more easily than with any other system, because without changing the tube its intensity can be varied without loss in efficiency.

This light could be used in subways and tunnels, in which cases the terminal-boxes would be eliminated and miles of tubing in 100-ft. lengths placed end to end and operated in parallel directly from the adjacent high-potential mains. The eyes of the motorman would then be subject only to a light of definite intensity and color.

Art galleries, surgical operating tables, exterior illumination of ferryboats, street lighting, shop show-windows, advertising signs—all these and many other industrial and artistic enterprises will be vastly benefited by the application of this tube light.

It is believed and hoped that the ideas advanced in this paper are simply in the direction of progress: that, aside from all theory, the facts show that electric illumination resulting from incandescent gases or vapors has vastly less limitations because their molecules or atoms are free to vibrate while those of solids are not, and therefore at the high temperatures necessary are subject to rupture: that "the signs of the times" clearly indicate that we have reached the beginning of the end of lighting by solid conductors and the end of the beginning of lighting by gaseous-conductors.

DISCUSSION ON " ELECTROLYSIS," AT NEW YORK, MARCH 1, 1907

(*Subject to final revision for the Transactions.*)

L. B. Stillwell: The results of Mr. Hayden's comprehensive and painstaking tests are particularly gratifying to all interested in the extensive use of electricity for railway purposes. While they show, however, that the electrolytic damage to subsurface metallic structures which alternating currents are liable to cause is practically negligible under ordinary circumstances, they illustrate also the fact that here, as elsewhere, special conditions may exist which call for the adoption of preventive measures. The method of protecting cable sheaths which Mr. Hayden suggests is ingenious and interesting. Quantitatively considered, however, his results indicate that it will rarely be necessary to adopt his plan of superimposing a continuous potential upon an alternating potential.

Mr. Knudson's paper and that of Mr. Rhodes have to do with electrolysis by continuous current. This subject is an old one and in the nature of things it is always with us. Unfortunately in its discussion the lawyer generally has been rather more prominent than the engineer. Too often also the engineers who have been retained by one or the other parties interested in litigation or threatened litigation, over actual or alleged damage by electrolysis, have approached the subject from a radically partisan viewpoint. Engineers representing the owners of water pipes or gas pipes have seriously recommended that street railway companies should be compelled to provide complete metallic circuits for their current, absolutely insulated from rails and ground. On the other hand, street railway companies, in many instances, have installed their plants apparently with absolute disregard of the effect of stray current upon the property of their neighbors; even going so far as deliberately to connect their track return to lead service pipes wherever opportunity offered.

Engineering is applied science; science is knowledge of facts. Nowhere better than in the meetings of this Institute can the essential facts ascertained by experiment or deduced by correct theory be discussed frankly and fairly, and nowhere better can engineering methods minimizing or preventing damage be worked out in a spirit of fairness to all concerned.

In the suit of the city of Dayton against the street railway company for alleged damage to water pipes owned by the city, Judge O. B. Brown in rendering his decision admirably stated the rights and duties of the respective parties in the following words:

> The use of the streets for water works purposes is obtained by legislative authority. The right of an electric railway to use the streets is from like authority. Each of these uses is beneficial to the public and each is entitled to use its respective rights, without interfering with the other, and it is clear that no conflict can occur between the two if each would remain within its own sphere and exercise its powers with

> due care and prudence. It is not necessary in arriving at a proper decision in this case to determine which should give way to the other. Both are legal and both are improtant and of almost equal necessity to the inhabitants of the city.
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> * * * * * * * * *
>
> Each should exercise its functions for the general good, exercising due care not to interfere with the duties and rights of the other.

There can be no question that in many of our cities and towns damage due to electrolysis is in progress which might be prevented by reasonable application of known principles and methods. That the prevention is not employed is due, in part, to our engineers, but perhaps still more to the general unwillingness of the management of electric railway companies to spend money in preventing damage which is not seen. This unwillingness to incur expenses in correcting conditions not realized by the executive management of the companies is naturally to be expected. The duty of the engineer is to exercise his influence to secure a realization of the fact that an ounce of prevention is worth a pound of cure, and to induce his client to take timely precautions to protect the interests of his neighbors, and, by so doing, to protect his own.

Mr. Rhodes' paper is an excellent theoretical discussion of the possibilities of an apparatus probably destined to do much more work in the future than it has in the past. Properly applied, it is of the greatest value in minimizing electrolytic damage under certain conditions. The plans of the Hudson Companies contemplate the use of boosters to prevent possible electrolytic damage to the metallic shells of the tube tunnels destined to connect the Borough of Manhattan and the New Jersey shore. The Interborough Rapid Transit Company is also proposing to use them for a similar purpose in connection with its tunnels under the East River.

While the papers of Messrs. Hayden and Rhodes are convincing and of special value, that of Mr. Knudson would seem decidely to require revision of methods employed before satisfactory conclusions can be drawn. As regards Fig. 6 of this paper, the method employed; namely, the increase of potential to keep current constant, notwithstanding the apparent tendency of the reinforced concrete to protect itself, seemingly makes the conclusions reached of little value. No proof whatever is presented that the splitting of the concrete blocks was due to electrolytic action, as no effort had been made to exclude other possible causes, for example, expansion due to chemical change in the concrete itself. It is important to ascertain the facts as regards electrolytic corrosion of iron or steel in concrete, but the paper as presented fails to establish them

Frank N. Waterman: We all know that electrolytic phenomena are so essentially mysterious to the average mind that it is almost impossible for the public to distinguish between true statements and false. Electrical engineers should, therefore, be extremely cautious about making statements that might mislead the layman. It is therefore peculiarly important that the discussion of the subject by the INSTITUTE should be careful and scientific, since its utterance will be regarded as authoritative. The papers by Messrs. Hayden and Rhodes are most gratifying in this respect, but the paper by Mr. Knudson contains much that cannot be considered as the last word on the subject.

Iron encased in concrete is like a battery electrode in a porous cup so far as insulation is concerned; of course current can be sent through it, and it can be made to take iron with it. Cement as a protector of iron acts both mechanically and chemically. If a current is introduced into the midst of it no protection is to be expected, unless by chemical action with the initial products of the decomposition a protective or highly resistant coating is formed which will restrict the flow of current. In Mr. Knudson's paper five samples of cement were used, but the author has not told us about the physical or chemical properties of the cement, how long it had been cast, or its age or condition when cast. Whether it contained free lime tending to make it develop expansion cracks, or whether its constitution predisposed it to shrinkage cracks, are not set forth. These facts are important, and should be carefully considered in accounting for the cracking of the blocks.

I should like to know the condition of the iron surfaces before weighing and casting—whether they were turned or filed bright or were coated with oxide grease and dirt; and, too, did the same person that did the original weighing do the final weighing? And how was the cement removed from the iron surface? It appears that the coating on the surface was not dissolved off but was scraped, in the case of the samples subjected to current, while the single specimen not subjected to current was not scraped. Therefore, I think it would be interesting to learn how much of the material set down as loss was original oxide and dirt, how much was natural corrosion, and how much good iron filings? The maximum depreciation as given is about 1.5 oz. in 3 lb. 7 oz., or less than two-thirds of the expected loss.

In the passage of current through the samples, Mr. Knudson says that a constant current was sent through, the voltage being remorselessly raised 1400% to effect the result. It seems to me that the raising of the voltage to that extent would in itself baffle the efforts to determine the utility of cement as a protector.

We are told that the cement cracked, it would be interesting and valuable to know whether a current will have such an effect on cement and if so to what particular action or influence it is due.

Fig. 6 suggests that the samples subjected to current very soon began to protect themselves, and that to maintain the current flow the voltage had to be raised to 42 volts, or 14 times the minimum energy; that is, to 4.2 watts. The surface of the pipe was about 0.45 sq. ft. or about 9.5 watts per square foot of iron if the resistance was concentrated at the surface. In the case of the salt-water specimen it seems that the voltage was increased 5.5 times.

Were these tests made with regard to temperature or the rise of temperatue due to the current? This, I think is worth considering, as the energy was so large as to cause foaming and evident heating.

So far from indicating that iron encased in concrete will be injured in practice, these curves seem to suggest that had the samples been subjected to anything like natural conditions they would promptly have protected themselves against damage. Under such conditions, voltages are not raised to many times normal values in order to force a definite current through; temperatures are kept at low and relatively constant values, the opposite electrode is not usually brought up to within a few inches of the iron, and the current concentrated along a radial line through the concrete as in these experiments.

If iron will protect itself against electrolytic action when encased in concrete, as the paper seems to indicate, the fact is interesting and important. If, on the other hand, it will not be materially protected, that fact is also interesting and important. But the paper gives us no basis for a positive opinion. The measurements seem to indicate that the iron will tend to protect itself, but unfortunately the method of experiment makes it quite impossible to say whether it will or not.

The author's conclusions on these experiments are most sweeping. Thus he concludes:

> If but a small fraction of an ampere of electricity passes from an interior metallic column or structure into concrete or masonry as usually made, there will be corrosion of the metal and disintegration of the concrete or masonry.

What the author calls a small fraction of an ampere amounted in fact to nearly 0.25 ampere to the square foot, or for the sake of comparison to 5,000 amperes per mile of 30-in. water main; in other words, a current which is extremely large compared with those likely to exist in practical conditions except under very exceptional circumstances. There does not seem to be any ground for the assumption that the current had anything to do with the cracking of the concrete, much less that it would under practical conditions have such an effect.

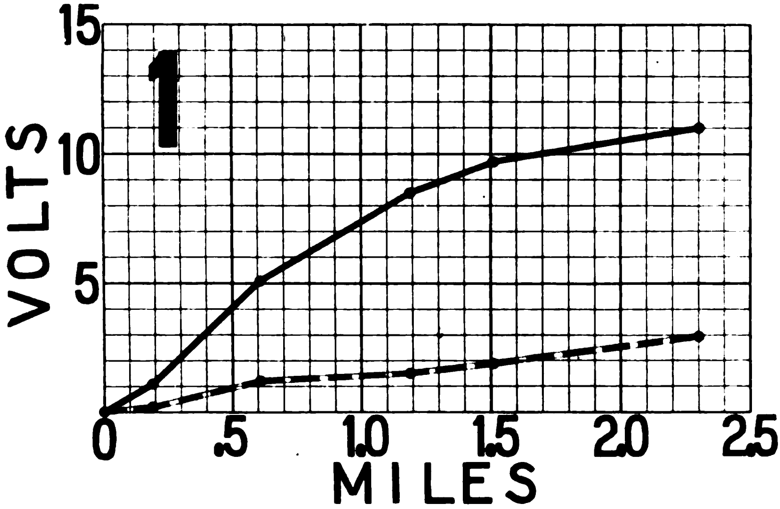
We are shown a picture of a corroded water-meter, but just what a corroded water-meter has to do with the subject of the paper is not quite clear. That an iron shell resting on the earth floor of a damp cellar for a sufficient period will be destroyed whether there is electric current in the neighborhood or not, is well known. Not the slightest proof is offered that this sample was in any way affected by current.

One thing in Mr. Rhodes' paper seems to me a very picturesque way of stating what all of us have encountered; namely, the enormous quantity of copper required appreciably to reduce the drop where the feeders parallel the track. The unit which he takes is the weight of copper of conductivity, equal to that of the rails. It is an impressive thing when one has had occasion to figure what that means. The natural result in such cases, where reduction of drop is necessary, is the negative booster. Unfortunately, we do not deal with the negative booster on the simple lines of the paper. We are not given roads which run straight from the power-house, and are uncomplicated by branches or network. Some systems can be reduced to a plurality of such lines, but the majority will involve a more or less complicated network. The distribution of current in a network is determined by constantly changing bond resistances, particularly where special work is not kept up. The negative booster offers an extremely interesting possibility in that connection. It gives the means, with reasonable watchfulness, of controlling the distribution of current in that network. The paper dealing as it does only with the single-trolley line, naturally does not bring that out. It shows the enormous gain in respect to reduction of earth currents, but does not show the other possibility of the negative booster; namely, the control of the distribution of the return current in the network, which is a feature in many cases of very great value, particularly in making it possible to reduce to a minimum the track drops in those regions where such current, as has escaped to the earth, is returning to the rails, thus giving a current density of minimum value in the pipes, at points where current is leaving them, that is where they are positive to the rails.

Paul Winsor: We think we have a pretty good railroad in Boston; well bonded, a good deal of return copper, and we follow it pretty closely. But in certain places we have bad conditions; the trouble we have had, unknown or unlooked for trouble, has taken place near the Harvard power station, where there is a marsh of salt water, and byond which, about a mile away, is the first car track in that direction. A large number of water mains are located nearby, but a careful study of the situation has reduced the electrolytic trouble most materially. The telephone company have taken great pains to survey their cables, and when they find a place where they think there is danger of electrolysis, they consult with our engineers, and we put in either a negative feeder or a connection to our rail. This removes the trouble. On our own cables we have cut the lead in many places, made special connections, and got rid of the trouble. The Metropolitan Water and Sewerage Board have some large pipes running into Boston. We studied the matter carefully with them, and finally put eleven insulating joints in those pipes. Some of the joints are of rubber, and some are of wood, ordinary bell and spigot joints, with ⅝ in. to ¾ in. of pine calking.

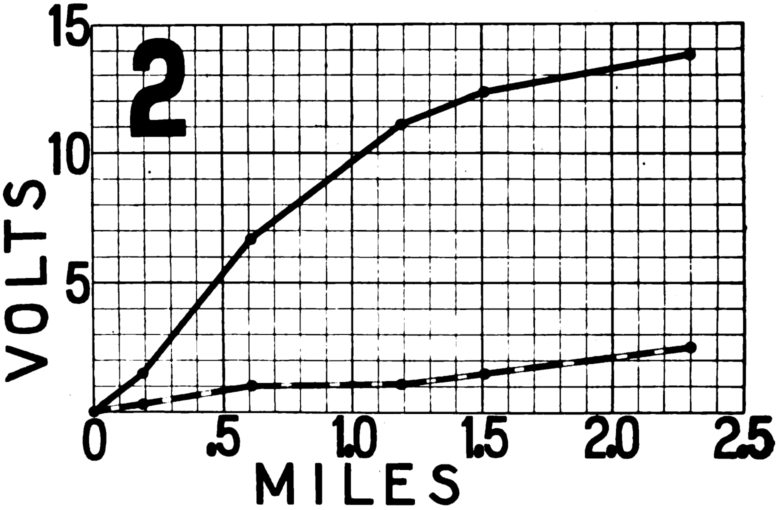
Some time ago we made some experiments in operating certain portions of our road on the three-wire system. Some of the data we got regarding the current in the neutral back to the station; that is, the return currents through the rails and underground structures, seem to me of interest in connection with the present discussion. As we thoroughly appreciate the practical difficulties of operating stations on a three-wire system, the matter is not offered as a panacea for the cure of electrolytic troubles, nor even as a practical method of operating; it is offered simply as of interest in the general discussion. Mr. Corning will present this part of the discussion.

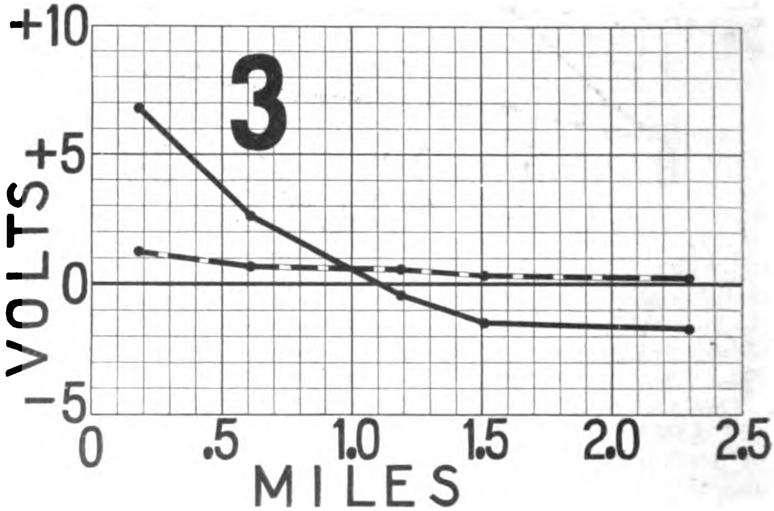
J. W. Corning: A few years ago in connection with the study of some power problems on our system, Mr. Winsor suggested that we investigate the feasibility of using the three-wire system. Some experiments were made, and in view of the papers to be presented this evening it was thought that a part of the results obtained would be a matter of interest to the members of the Institute. These results appear in graphical form in Figs. 1 to 15.



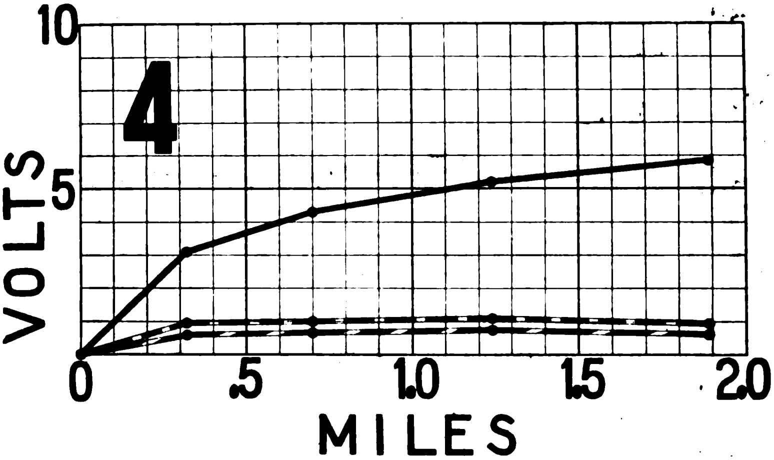
Our system is supplied with power from ten power stations and is divided into upwards of 70 feeder sections. In order to explain these results more intelligently, I will call your attention to Figs. 14 and 15 comprising nine of these feeder sections fed by the Harvard Power Station in Cambridge. You will notice from these maps that the dash lines indicate the boundaries of the feeder sections, the numbers of which appear. The heavy lines indicate tracks. Passing through this district from one side to the other will be seen depicted some 48-in. water mains The power station location is indicated by the star (*).

We operate on the two-wire single-trolley grounded-return system. Fig. 14 represents the ordinary relation between feeder sections with this system. Referring now to Fig. 15, it will be noted that certain of the feeder sections have been shaded.





In the experiments referred to these sections were supplied from this power station by current from a generator connected in three-wire relation with the rest of the station. No line change was made in the feeder sections beyond installing an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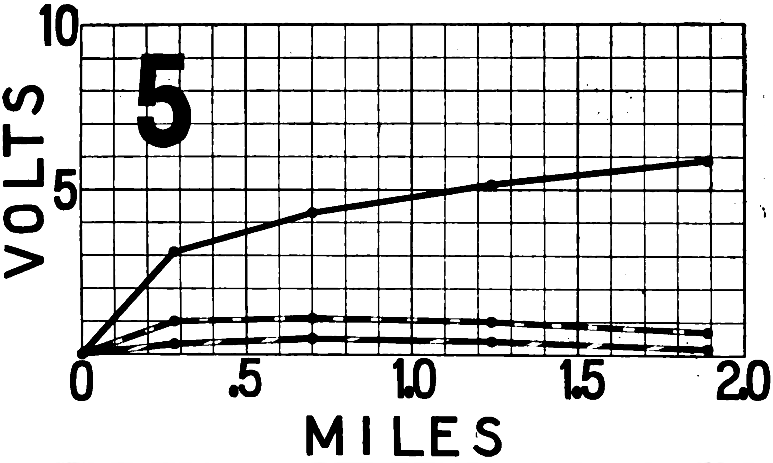
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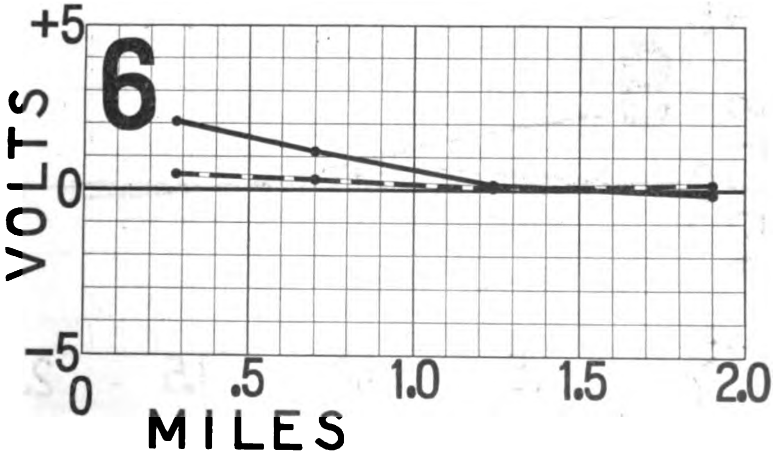
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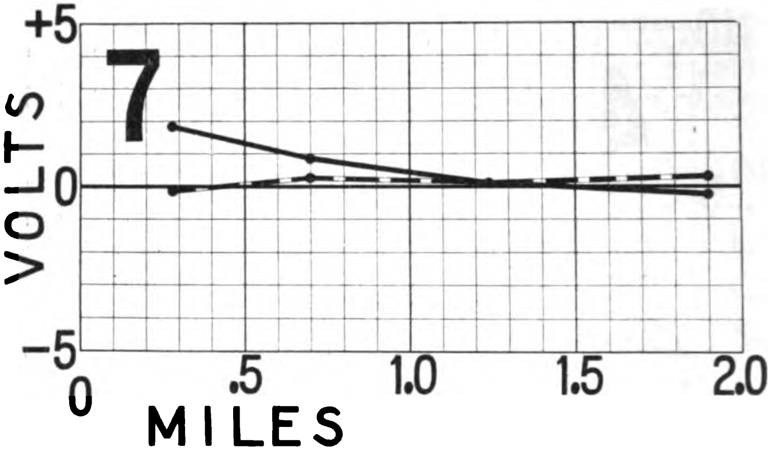
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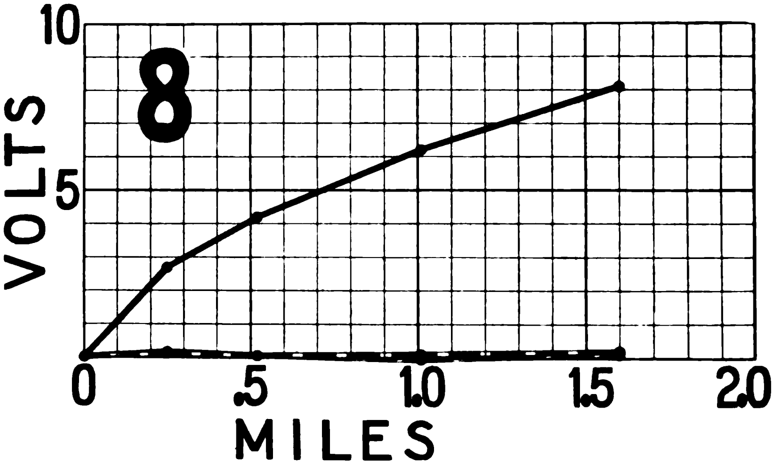
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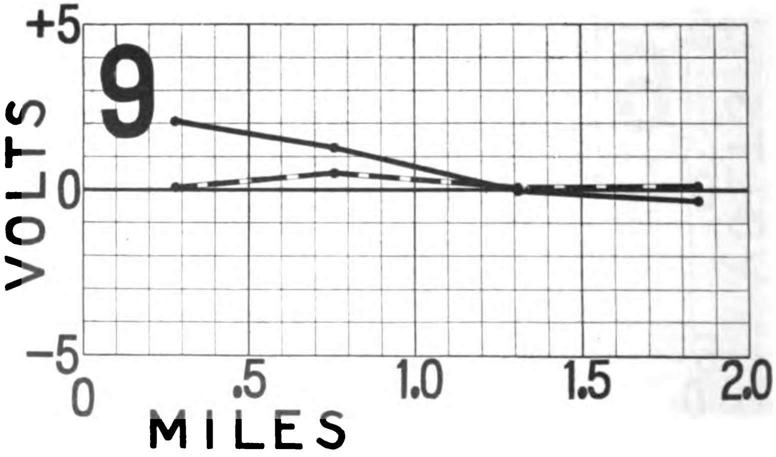
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additional set of insulating joints in the trolley wire at the points of intersection of positive and negative sections.

For the purpose of our investigations, test-wires were run from the power station in three directions for a distance of from 1.5 to 2.5 miles, and simultaneous readings taken at several points along the line, under both two-wire and three-wire operation. The observations that are interesting in connection with the subject this evening are:

a. Return drop,

b. Potential difference between pipe and rail.

c. Current flowing on pipe.

The observations under two-wire and three-wire operation were taken about two hours apart for a period of one-half hour each, the endeavor being to have the loads on the individual feeder sections as nearly as possible the same throughout both sets of observations.

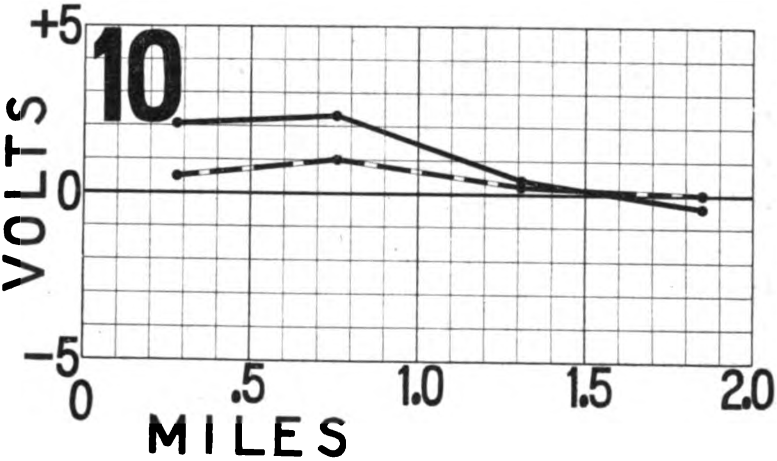
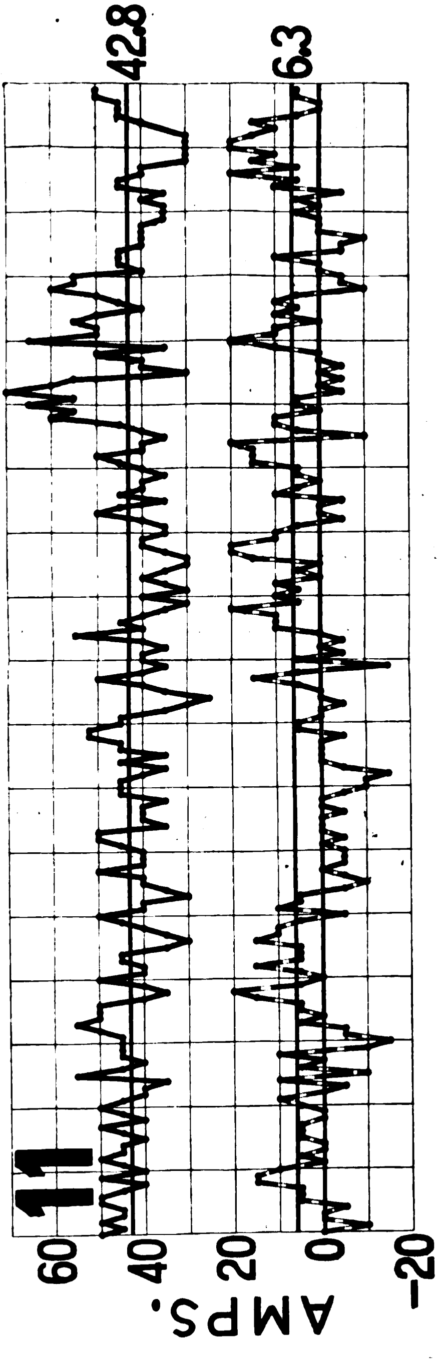


Fig. 1 shows the return drop to the power station from a point about 2.25 miles distant, under two-wire and three-wire operation. As before stated, the results are averages of readings taken at intervals of 10 seconds throughout a period of 30 minutes. The load on the shaded sections of Fig. — under two-wire and three-wire operation are as shown in the following table:

TABLE 1

Average load on section.

Section.	Two-wire.	Three-wire.
70	246.0	222.0
71	183.6	133.2
73	263.6	251.9
90	413.0	411.0
91	271.0	249.0
Totals.....	1377.2	1267.1


42.8
6.3
11
60
40
20
0
-20
AMPS.

From this table it will be seen that the conditions with respect to load are almost identical in both cases. It will be noted that the return drop under two-wire operation, represented by the full line, was reduced to that under three-wire operation, represented by the dash line, the drop throughout this length being reduced by about 83%.

Fig. 2 gives the results of a test which was repeated on another day in which practically the same results were obtained. The following table gives the loads in the several feeder sections:

TABLE 2

	Average load on section.	
Section.	Two-wire.	Three-wire.
70	278.3	305.2
71	196.9	303.2
73	272.6	275.0
90	488.0	516.0
91	325.0	339.0
Totals.....	1560.8	1738.4

Fig. 3 gives the potential relation between pipe and rail along the line of the first test-wire. The full line represents the relation under two-wire operation, and the dash line the relation under three-wire operation, values above the zero line referring to positive condition of pipes and those below the line to negative condition of pipes. It will be seen that the high reading obtained near the power station has been reduced very materially, although at the same time the pipe has been rendered positive throughout the whole length under consideration by a gradually decreasing amount. The loads in the several shaded feeder sections under two-wire and three-wire operation while the above test was being made are shown in Table 3.

TABLE 3

	Average load on section.	
Section.	Two-wire.	Three-wire.
70	245.2	266.6
71	145.2	189.2
73	231.0	295.2
90	524.0	527.0
91	378.0	329.0
Totals.....	1523.4	1607.0

Figs. 4, 5, 6, and 7 give results obtained along the second test-wire. Figs. 4 and 5 show return-drop relations on two different days. The current relations in the several shaded feeder sections for Figs. 4 and 5 are as shown in Tables 4 and 5

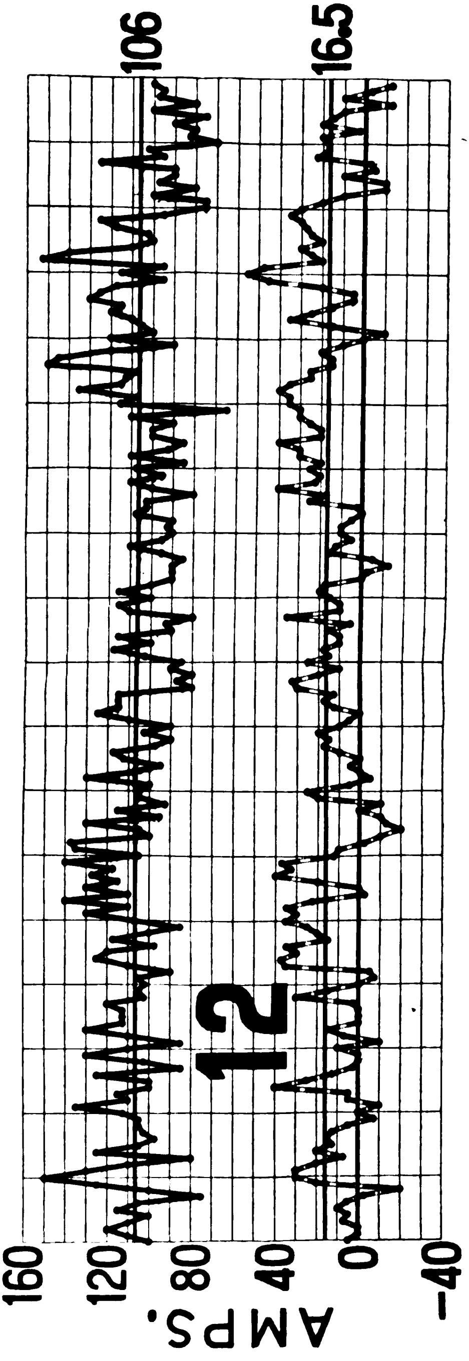

106
16.5
12
160
120
80
40
0
-40
AMPS.

TABLE 4

Average load on section.		
Section.	Two wire.	Three-wire.
70	215	208
71	136	149
73	241	262
90	480	454
91	266	300
Totals.....	1338	1373

TABLE 5

Average load on section.		
Section.	Two-wire.	Three-wire.
70	224.6	181.9
71	152.6	134.6
73	232.4	232.6
90	455.6	464.0
91	264.0	302.0
Totals.....	1329.2	1315.1

Attention is called to two sets of results, in each case under three-wire operation. While the upper set of observations was being taken, section 70 was feeding in the usual manner; whereas, while the lower set of observations was being taken it was fed from the other side of the three-wire system.

Figs. 6 and 7 show the potential relations on the pipe along the line of the second test-wire under two-wire and three-wire operation, and it is clearly seen that in these cases the potential differences between pipe and rail have been almost eliminated. The load relations of the sections while these observations were being taken are shown in Tables 6 and 7.

TABLE 6

Average load on section.		
Section.	Two-wire.	Three-wire.
70	234	199
71	113	111
73	284	285
90	445	404
91	249	277
Totals.....	1325	1276

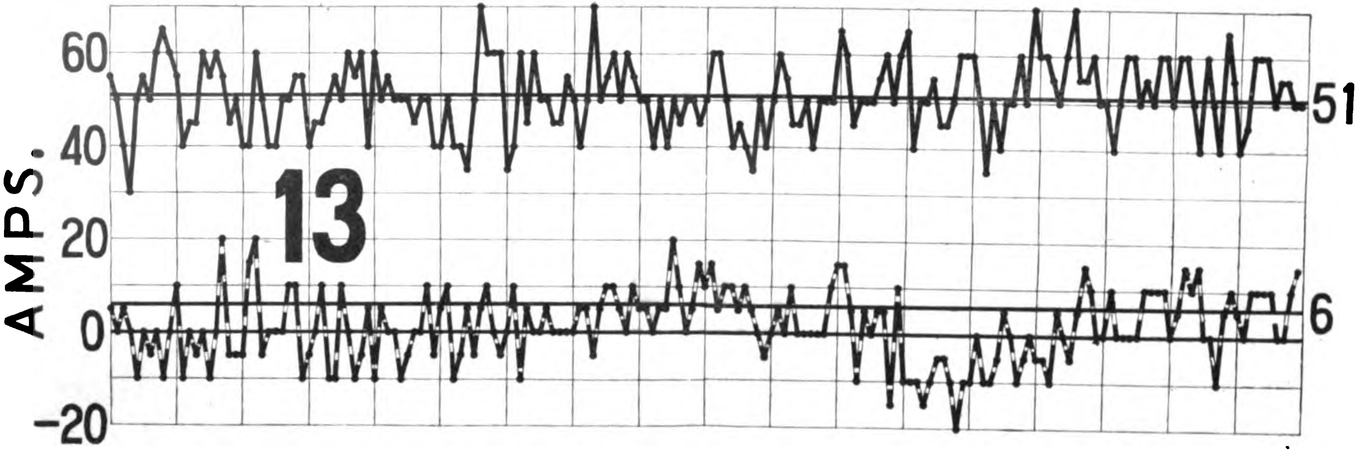

AMPS.
60
40
20
0
−20
13
51
6

TABLE 7

Average load on section.		
Section.	Two-wire.	Three-wire.
70	205	267
71	190	199
73	301	235
90	488	536
91	384	370
Totals.....	1568	1607

Fig. 8 gives the return drop along the line of the third test-wire. While the three-wire system was in operation, section 70 was fed part of the time from one side and the rest of the time from the other. The results are as shown. It will be seen that the return drop in this case was practically wiped out, the three-wire potential curve practically coinciding with the zero line. The effect of reversing section 70 in this case was not as great as it was in the last instance, but is just noticeable. The load on the several sections while these results were being taken is shown in Table 8:

TABLE 8

Average load on section.		
Section.	Two-wire.	Three-wire.
70	286.	321
71	170.6	199
73	280	236
90	627	600
91	372	380
Totals.....	1735.6	1736

Figs. 9 and 10 show the effect on the pipe potential in this district of three-wire operation as compared with two-wire operation, and similar relations of potentials are observed as have been observed in the previous cases.

I would now call your attention to Figs. 11, 12, and 13, which show readings of current flowing on the large mains which traverse the district in question under two-wire and three-wire operation. These readings were taken for a period of 30 minutes at intervals of 10 seconds. It will be seen in Fig. 11 that under two-wire operation the average current flowing on the pipe was 42.8 amperes, with a maximum of 70 amperes. Under three-wire operation this current was reduced to an average of 6.3 amperes, and a maximum of 20 amperes. On Fig. 12 an average current of 106 amperes, with a maximum of 155 amperes is reduced by three-wire operation to an average of 16.5 amperes and a maximum of 55 amperes. In Fig. 13 an average current of 51 amperes, with a maximum of 70 amperes under two-wire operation, is reduced by three-wire operation to an average of 6 amperes and a maximum of 20 amperes. The results in each one of these last three figures were taken at a different point on these pipes, the current being calculated from the resistance of the pipe, and the potential drop along a single length, not including joints. In the case of the three-wire operation the averages given are averages of all observations, those below the line being taken with a positive sign. In these three cases the three-wire operation shows a reduction in current flowing on the pipe of 85, 85, and 88% respectively.

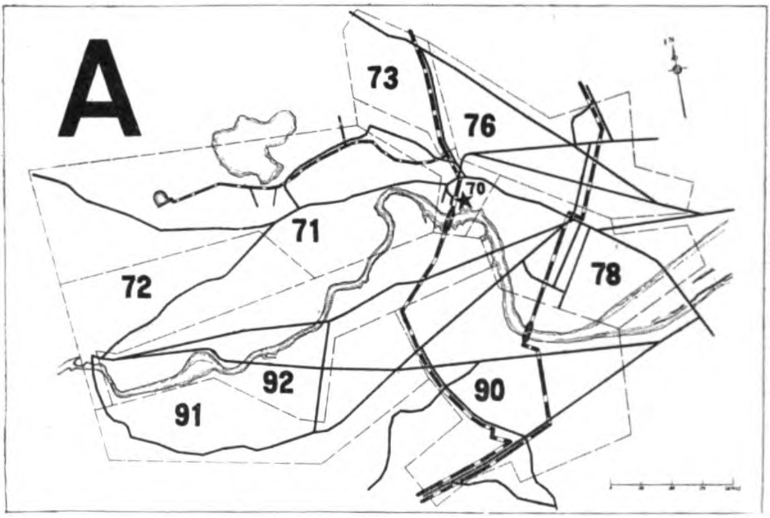


Fig. 14.

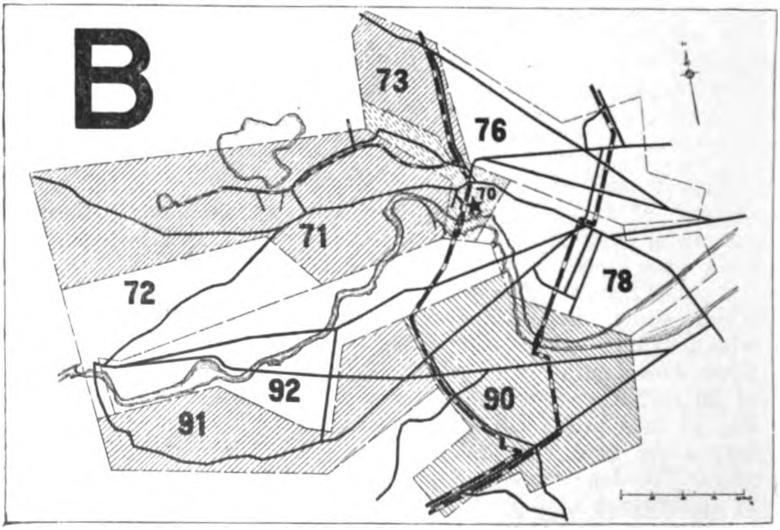


Fig. 15.

S. M. Kintner: It is satisfactory to find that the results of Mr. Hayden's tests agree with the results of tests that I made some two or three years ago.* I made tests quite similar to those reported by Mr. Hayden, though not so many different kinds of solutions were tried. The laboratory tests showed the following results:

1. That the loss was not directly proportional to the ampere-hours, as repeated weighings of the same plates after equal ampere-hours of current action failed to show equal losses.
2. That the shape of the plates had a very decided effect upon the results obtained, the edges being by far the most active part of the terminals. The best results were obtained with terminals mounted so as to form two sides of the box containing the electrolyte, the rest of the box being of impregnated wood. The terminal plates were approximately six inches square.
3. That it was necessary to have a duplicate cell for every one subjected to the alternating-current electrolysis, the duplicate being used to determine the chemical action alone. Attempts to reduce the corrosion loss to so much per unit surface, and thus correct for losses in various size cells, gave very inconsistent results.
4. That the loss on the so-called "gain plate" of a cell in which a sodium chloride solution and iron terminals were used, when subjected to the action of a direct current, was greater than the losses on similar plates subjected to alternating currents.
5. That the residue in cells, such as the last described, showed a very marked difference when analyzed chemically. The analyses of residue for the cells subjected to chemical corrosion only, and those subjected to the alternating current action, were very similar, while that of the direct current cell was very different.

Laboratory experiments in which cells were used were carried on for several months, with results somewhat similar to those obtained by Mr. Hayden. The broad general conclusions reached were that:

a. For iron and steel there was in general little or no loss greater than the chemical corrosion.

b. But for lead and tin-lead, such as employed in cable sheaths, there was a slight loss which varied from one quarter to one half of one per cent. of what would be obtained from direct current under similar circumstances.

A long-time test was then undertaken in which pipes of from 4 to 6 feet in length were buried for a period of one year. During all this time an alternating current of 25 cycles and 25 volts was applied between each pair of pipes. In this test, pairs of pipes of wrought iron, cast iron, and lead were used. Each pipe was carefully weighed and marked before it was buried, and was weighed again after one year's test. The losses in weight of the several pipes were not materially different, it being on the average the same for the pipes subjected to the alternating current as for those subjected to corrosion only. It is believed that a test of the kind just mentioned is much more representative of operating conditions than any that can be carried out in a laboratory.

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*Electric Club Journal, November, 1905.

Careful visual inspection of the pipes as they were removed from the ground failed to show any difference between those subjected to the alternating currents and those which were not.

Referring to Mr. Hayden's conclusions regarding the electrolytic effect of current densities in amperes per square foot, I think that the current densities mentioned by Mr. Hayden are very unlikely to exist in actual service. I found that it required about 260 volts to force only 30 amperes of current between two terminals each of 20 square feet of surface. The terminals were only 6 feet apart and the earth was exceedingly moist; the water was also very impure, as a large part of it was surface drainage. Another test with similar size terminals placed in a less favorable location gave only about 7 amperes for 260 volts.

It is the writer's opinion that the alternating current, so far as practical service conditions are concerned, will not cause serious electrolytic damage to pipes.

Calvert Townley: With reference to general electrolytic problems, I think we have all been too much afraid of them. When attacked with the same vigor that is commonly brought to bear on other problems connected with the generation and distribution of electricity, electrolytic questions show themselves no more difficult of solution. While not desiring to belittle the damage which may occur from neglect to take proper precautions against the electrolytic action of direct currents, I do think it is time to discourage giving them disproportionate importance, and timidity in their handling. The public has been led to believe that electrolysis going on secretly and continuously under our feet is much to be dreaded; but if those who have to do with underground structures liable to electrolytic attack, and those who have to do with the generation of current which is likely to attack such structures, will jointly take pains to ascertain by suitable measurements what the existing conditions are, and will take such reasonable precautions to minimize the troubles as the state of the art permits, I believe that the seriousness of the situation will be largely, if not entirely, eliminated. As engineers, our efforts should be to bring the facts before all interested parties, and let it be known that, treated intelligently and carefully, electrolytic troubles can be largely prevented.

I get much encouragement from Mr. Hayden's paper. I have not known much about alternating-current electrolysis, but have had a general feeling that it was insignificantly small.

Mr. Hayden's paper, as well as Mr. Kintner's discussion, greatly strengthens this feeling. As far as I know, there is yet to be reported the first case of trouble anywhere in practical service from electrolysis due to alternating currents.

I understand that in protecting the lead sheathing of their cables from direct-current electrolysis, the telephone companies have adopted a method which they have found to be entirely satisfactory; namely, where the cable is positive to the return circuit they connect the lead sheath of the cable to that circuit by a metallic conductor or bond, so that any difference of potential that may exist between the lead sheath and the return circuit is practically eliminated. No attention is paid to the sheath where it bears a negative relation to the return circuit; that is, where the tendency of the return current is to flow from, say, the rail of a trolley road to the sheath. But where the tendency of the current is to flow from the sheath to rail, and electrolytic damage may occur in consequence, a bond is inserted. Now the tendency to flow from sheath to rail is not concentrated at any one point. The positive relation frequently extends over a considerable area, although practice has shown that electrolytic damage may be prevented by the insertion of a bond only at some one central location. Obviously, it follows, therefore, that the additional drop in the lead sheath from the outlying territory of the positive area to the central bond can be neglected, although in many cases it must represent an appreciable potential. Mr. Hayden has shown that under the most unfavorable conditions, alternating-current electrolysis will not exceed one per cent., and will seldom equal as much as one-half of one per cent. of the electrolytic action of the direct current of like volume.

In the light of the foregoing, then, it becomes pertinent to inquire whether the total tendency towards alternating-current eletrolytic action is any greater than the residual tendency for such action from direct currents in outlying parts of the positive district, and which it has been found are practically negligible. I think we can all take a great deal of encouragement from the very small amount of electrolytic action found to take place under the most unfavorable conditions of Mr. Hayden's test, and from the interesting comments contained in Mr. Kintner's discussion.

George F. Sever: It is fortunate that we should have so valuable a discussion on this subject from Boston, because our first real knowledge of electrolytic troubles came from Boston some years ago through a valuable paper by Mr. Farnham.* He investigated this subject most thoroughly in the interest of the telephone company, and the West End Railroad of Boston, now the Boston Elevated, assisted him materially in his investigation. Since that time, the subject has been very carefully followed up in Boston, as well as in many other places. If the interests in all other cities, such as New York, Philadelphia, Chicago, St. Louis, and Pittsburg, should study this question from an engineering standpoint, we would have but little contention as to the proper methods to apply in remedying the supposed difficulty.

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*TRANSACTIONS, A. I. E. E., 1891, Vol. x., p. 191.

I speak from the standpoint of a municipal engineer, who finds in his city some isolated indications of electrolysis. The engineer, whether he represents the water or gas interests, reports this difficulty, and possibly a suit against the local railroad company results. If the court reaches any decision, whatever it may be, there is no assurance that sub-surface conductors are not incurring further damage. In my opinion—and I have carried this out in practice in the city— the only way to handle the situation is for all parties in interest with their engineers to agree upon a policy, and to study the situation carefully and together, and endeavor to reduce the difficulty wherever it appears. I think we make too much of electrolytic troubles; I think those who stimulate this idea in the minds of engineers do not realize what electrical engineers can do to remedy the supposed difficulty. Some time ago the American Water Works Association published a long and interesting report signed by three eminent engineers, recommending that every trolley road in the country be changed from the single overhead trolley system to the double-trolley system, as a sure remedy for electrolytic troubles. That interesting document is referred to in almost every electrolysis case; having the opinion of these three eminent engineers behind it, it is very impressive to the authorities. I think the Institute should take some recognition of this report, to the end of pointing out that the electrical engineer, in coöperation with the municipal engineers or water works engineers, can mitigate and cure the difficulty. In one city that I know of the water system is supposed to be undergoing continuous damage, whereas the gas system owned by the city has not indicated that any damage is occurring to its system.

Mr. Hayden's paper prompts me to cite the result of some tests and investigations made at Columbia University in 1904, on alternating currents as producing electrolytic action. At that time we had available only 60-cycle current. We arranged cells containing certain solutions such as sulphates, chlorides, carbonates, and nitrates of different metals, and passed current through them by means of lead plates. From the results obtained we arrived at the following conclusions:

1. That alternating currents can cause a slight electrolytic action. 2. That the rate of this action is very much slower than with direct currents of the same value. 3. When insoluble or semisoluble salts are formed, the rate of action with a given current strength decreases with the passage of time. 4. That the resistance of the cell decreases with increasing current

strength for alternating current as well as for direct current. 5. That the resistance is not only in the liquid itself, but particularly in the contact layer where the electrode and electrolyte meet.

Variations in the density of the current, or of the electrolyte, unless excessive, have no marked effect. Unless subsequent investigations shall bring to light differences likely to exist in the earth, in which corrosive action is more vigorous than between lead and the common salts of the alkali metals—and no such combinations are known as applied to direct-current railway operation—the corrosive action of alternating currents on sub-surface metal structures may be assumed to be negligible. This investigation is being supplemented by a further one for lower frequencies, and I trust we shall be able later to report the results of that investigation.

Albert F. Ganz: The experiments described by Mr. Hayden show that with an alternating-current electrolytic corrosion is generally a very small fraction of that which would be produced by a direct current of the same strength and under the same conditions. The action is explained by the statement that the corrosive effect of the positive half wave of current is not entirely reversed by the reconstructive action of the succeeding negative half wave. The reason for this lies probably in the fact that a portion of the products of the electrolysis, produced by the current during the positive half cycle, diffuses away so that the negative half wave of current does not quite reverse the action of the positive half wave. Since these rates of diffusion vary greatly with different materials, the per cent. of direct-current electrolysis produced by an alternating current varies greatly with different electrolytes. On this theory the effect of increasing the frequency would be to diminish the electrolysis. In general this has been found to be the case. The rate of diffusion of the products of electrolysis in the case of metals in the soil may also be governed by other conditions, such as by the amount of moisture present, temperature, etc., and this would seem to be so judging from the widely varying quantitative results which have been found by different investigators.

The suggested protective measure of superimposing a small direct current upon the alternating current so as to add to the effect of the negative half wave sufficiently to neutralize completely the corrosive action of the positive half wave is certainly very interesting, but does not seem to me to be a desirable thing to do in practice, as I understand the proposition, because it would mean deliberately to send a stray direct current through the ground and to have this enter the metal to be protected and return by way of this metal. This stray direct current, while small in percentage of the alternating current to be counteracted, in its passage through the ground may in itself be a source of electrolytic danger to other underground metal.

Referring to Mr. Knudson's paper, the curve shown in Fig. 7 is of importance inasmuch as it shows that concrete absorbs a considerable quantity of water and becomes an electrolytic conductor of comparatively low resistance, so that a few volts of electromotive force between a metal imbedded in wet concrete and the surrounding water or wet soil is sufficient to set up a current. It also explains why attempts to protect pipes from electrolysis by embedding them in concrete have failed.

Mr. Rhodes' paper brings out the very important fact that the disposing of return feeder copper is quite as important as the weight of return feeder copper used in the effort to minimize stray currents. The calculations given show clearly that the way to obtain a minimum of stray current from the grounded rails of a single-trolley electric road is to insulate the negative bus-bar, and to employ two or more insulated return feeders either so proportioned in resistance or provided with negative boosters as to produce equal potentials at their connecting points to the rails. This method results in minimizing the potential differences in the rails, and for this reason also minimizes stray currents from the rails.

Mr. Rhodes assumes that the only resistance encountered is the contact resistance between the rail and ground, which is on the safe side, as it gives values for the stray currents which are too large; as a matter of fact the soil, especially when dry and sandy, has considerable resistance.

The question of electrolysis from stray railway currents has been very carefully investigated in Germany by a committee of the German Society of Gas and Water Engineers, who have already issued three annual reports. Translations of these reports for the years 1904 and 1905 are published in abstract in the *Report on Electrolysis* of the American Gas Light Association. The German committee have formulated a set of rules for electric trolley roads which are designed to prevent trouble from electrolysis due to stray currents.

These rules require permanent bonding of the rails so that the resistance of the finished track does not exceed the resistance of an equivalent unjointed track by more than 20 per cent. They also require that the resistance between the rail return and the ground be made as great as possible and to this end forbid the deliberate grounding of the negative bus-bar and of any part of the return system. They also forbid the bonding of the rails to any underground pipes or other metals.

Great stress is laid in these rules upon the installation of return feeders in such a manner as to minimize the rail potentials; the following five of these rules relate directly to the return feeders and I will repeat them here because they bear directly upon Mr. Rhodes' paper:

3. *Potential Difference in the Rail Network.* The potential difference in the rail network must be limited to a certain prescribed amount, which must not be exceeded with the greatest or most unfavorable loading of the return circuit.

The greatest permissible potential difference must be determined for each place separately, for it depends upon local conditions, such as the nature of the soil, the location and resistance of the pipes between points of highest and lowest potentials, the position of the pipes with respect to the rails, etc. In special cases, this greatest permissible potential difference may be different in different sections of a rail system.

For the present this maximum permissible potential difference in the rail network may be taken as *one volt*; this figure to be the average of readings for ten minutes during a period of full load.

4. *Return Conductors.* Where the rails alone are not sufficient for the return current, without allowing the potential difference to exceed the prescribed amount, extra return conductors must be provided.

These return conductors must be so numerous and so planned that, in conjunction with good conductivity of the rail network, they prevent the potential difference in the rails from exceeding the prescribed amount.

The points where the return conductors are connected to the rails should be located as far from the pipes as possible.

The return conductors must be insulated and of sufficient size to return the current with only a small drop in voltage; so that, if an occasional change in the distribution of the currents occurs, no excessive difference in the potentials at the connecting-points of the return conductors will be produced.

The return conductors should have a cross-section at least equal to that of the outgoing conductors; where conditions require a number of return conductors, it may be better to make them of larger cross-section than the outgoing conductors.

6. *Adjustability of the Return Conductors.* An essential condition for minimizing the potential difference in the rails, and therefore the stray currents, is that the potentials be equalized at all points where return conductors are connected to the rails. The resistance of each return conductor must, therefore, be proportional to the strength of current which it has to carry. For this purpose, each return conductor must be provided with an adjustable resistance (or negative booster) so that the product of current and resistance may be made the same for all return conductors.

7. *Negative Boosters* (*Sucker Dynamos*). Negative boosters are to be recommended, particularly for the purpose of automatically regulating the rail potentials at the connecting-points of the return conductors in districts where the return conductors are liable to be frequently or seriously overloaded.

8. *Controlling Arrangements.* Test wires must be led to the distributing station from all points where return conductors are connected to the rails, and from all points of relatively highest potentials in the rail network (points between two return connections and points at the end of the track). By connecting a voltmeter, it must be always possible to determine the potentials of these points in the rails. Arrangements must also be provided so that the current in any one of the return conductors can be measured at any time, etc.

The laying out of a proper system of insulated return feeders has been frequently neglected in this country, and even where insulated return feeders have been intsalled they have only in rare cases been properly proportioned for equal drop in potential. The usual method is to connect the rails with the negative bus-bar at the station with large copper cables, and in large installations to run out additional return feeders from these bus-bars to points on the rails distant from the station. The drop in potential in each of these long return feeders establishes points of higher potentials in the rails at these connecting points than exist in the rails at the station. The tendency is therefore for currents to leave the rails in these distant points of higher potentials, pass through the ground and buried metals, and return to the rails in the vicinity of the station.

Great improvements in the ground return circuits could generally be obtained in most of our trolley roads if these rules were followed at least to the extent of insulating bus-bars, removing all bonds to pipes, and installing a properly proportioned system of return feeders. The use of adjustable resistances in the return feeders is not a practicable arrangement for the large currents generally used on American roads. The use of negative boosters as suggested by Mr. Rhodes is, however, entirely practicable, and when applied with a judicious number of insulated return feeders will tend greatly to minimize stray currents. This is well illustrated by the curve in Fig. 8 of Mr. Rhodes' paper, which curve shows the percentage of stray current with various numbers of return feeders, and is based on the assumption of equal potentials at the connecting-points of these return feeders.

Mr. Rhodes says that very little is gained by using more than two return feeders. I do not believe that this is so on a large and extensive system. Referring to the curve in Fig. 8 it is seen that three return feeders will reduce by half the stray current with two return feeders, and four return feeders will again reduce by half the stray currents produced with three return feeders. In a large system the stray currents obtained with two return feeders may still be a dangerous stray current making a larger number of return feeders imperative.

C. P. Steinmetz: Electrolysis is a branch of electrical engineering that has the misfortune to be of special popular interest. It has been exploited very thoroughly by the " yellow " press, gas pipes, water pipes, bridge piers—all these public and private utilities have been attacked and destroyed, in the newspapers, by this electrochemical phenomenon. Fortunately, iron is a material which is not so easily attacked by electrolytic action; wrought iron is not attacked very badly, steel very much less, and cast-iron is hardly attacked at all. For the electrical engineer, the problem of electrolysis is not the problem of protecting the rails —even the gas or water pipes can in general very well look out for themselves—for with a reasonable use of negative or ground feeders there is little danger. The greatest danger of electrolytic action is in the case of the lead cables of the telephone system. The underground metal structures which are suffering most are the underground lead cables—the telephone cables. The power cables are relatively less affected, because they are better protected in subways, conduits, manholes, etc., and furthermore it is not economical to let a power cable lie idle. As long as it carries current it is at a temperature above that of the ground, and condensation is not likely to occur at or near it. But condensation and consequent electrolytic action do occur at or near a telephone cable.

The telephone companies have worked out, I understand, a system of protection by maintaining the cable negative against ground, by connecting it to the negative terminal. For this protection it is not, as was stated here in the discussion, necessary to see that no current passes between the lead cable and the rail. That cannnot be done, and current may pass; but the protection is perfect and absolute by making the cable throughout its whole extension more negative than the surrounding ground. As long as the lead cable armor is maintained at a potential, however slight, negative against the ground, there is no electrolytic corrosion, although current may pass. In this manner cables have been protected. Where no ground is used at the negative terminal of the dynamo, but only return feeders, by having negative feeders lead to the cables the whole cable system can be maintained at a negative potential against ground; even with a limited number of connections between the cable and negative terminal, the cable can be absolutely protected.

This shows the importance of considering alternating-current electrolysis. It has been stated in the discussion that alternating current electrolysis does not need to be feared, because it is less than one per cent. of direct-current electrolysis. I understand from those who know about the electrolytic attack, and the danger of it, with lead cables, that in many cases an electrolytic corrosion of telephone cables amounting to one-half per cent. of the direct-current action, would in a very short time be destructive. Therefore, fear is expressed that even with the greatly reduced electrolytic corrosion of the alternating-current the corrosion would still be destructive and harmful to telephone cables. It is said that against direct-current the lead cables can be protected, but against alternating-current it does not seem possible. This is the importance of the last section of Mr. Hayden's paper, which shows that even against alternating-current lead cables can be protected. I believe that with the introduction of single-phase railways this protection will become necessary in many cases, even with an electrolytic action equal only to one-half per cent. of direct-current electrolysis.

It has been stated that the current densities in actual practice between cable and ground may not be as high as chosen in Mr. Hayden's tests. I beg to differ from that. If a cable is laid in the ground through its whole length, the total current from the cable to the ground distributed over the whole surface of the cable would give a low current density, but that is rarely the case with lead-covered cables. Laid in a conduit, the cable is, for most of its length, fairly well insulated from the ground, and it is only in isolated places where moisture condenses, or otherwise the cable comes in conducting contact with the ground, that current enters or leaves the cable to ground. In these spots the current density may be very high, and rapid destruction would take place if no protective action were resorted to. It is true that such a protective direct-current would somewhere else eat up the metal. But this is necessarily so, and when we protect lead cables against electrolysis by making them negative, it means that we prevent the electrolysis at one point by making it take place somewhere else. But this other place will be the rails which can stand it, because even with direct-current electrolysis the total amount of corrosion, when distributed over the whole extent of rails, in the rail return does not amount to anything compared with the mechanical wear. We may well neglect it altogether. It is only in the thin cable sheaths of lead cables at exposed places where damage may result, and the stray superimposed direct-current would not need to be feared in its electrolytic effect on the positive side of the rail return.

As stated, the problem is that of guarding against electrolysis of lead cables. Guarding against electrolysis of iron rails and gas and water pipes is not very difficult and with alternating-currents needs hardly to be considered, except in very extreme cases.

To protect against the alternating-current by a superposed direct-current may be done in the same manner as Mr. Rhodes has shown in his paper—lay out a system of negative feeders for an underground cable system, so as to insure that the total stray alternating current will be within the limits of protective action of the total direct-current superimposed upon it I think that a further investigation similar to that given by Mr. Rhodes' paper may well be carried out and will result in an intelligent arrangement for protection of the lead cable system against alternating-current electrolysis.

Mr. Knudson's paper has been severely attacked, but it all depends how you look at it. I do not think that this paper can be considered as a conclusive decision on electrolytic corrosion of iron in concrete, but merely as some preliminary experiments which show that a further investigation is very desirable and should be made. All that the paper really shows is that a piece of iron in a concrete block is affected differently if a direct-current is made to flow, than if no current is made to flow. The next questions to answer would be: what is really taking place? How does it take place? What is the meaning of it? How can we guard against it? The paper does not state what is taking place; why the cement block cracked. It may be electrolytic corrosion of the iron, the formation of oxides which occupy a larger volume and so increase the size of the iron, and cause mechanical destruction by the irresistible force of the increase of volume which leads to cracking. It may also be electrolytic action resulting in the production of chemical compounds. We may think of chlorine attacking the concrete and softening it, or it may be still other actions; in short, the action of cement requires further investigation. In Mr. Hayden's paper also cement is mentioned; there the curious effect, where cement is not used by itself as in a concrete block, but added to soil, is that it increases the spontaneous corrosion of lead. That also may be a chemical action exerted by the cement on the soil. It also affects greatly the electrolytic action, different at 60 cycles from that at 25 cycles. In short, the whole phenomena resulting from stray currents on concrete structures may well be further investigated in view of the importance of concrete as structural material in the ground.

In regard to the protection, by negative feeders and the permissible potential drop against ground, the specifications of the German engineers are certainly very safe. If the potential difference between rail and ground in the return circuit is kept below one volt, there will be no trouble from electrolysis, because the pressure is below the dissociation voltage of water. This recommendation deserves to be classed with the recommendation of the American Water Works Association Committee of Engineers, in which they recommend the double-return trolley. The German recommendation is not quite as practicable, however, because one volt potential difference is impossible. I understand in England that the rail return drop has been restricted to seven volts. Those who have figured on negative feeders for any railway system know how handicapped the electrical railroads are with regard to this specification of seven volts return. To restrict it to one volt, if that is really the recommendation of the German engineers, would appear ridiculous. I do not think it can be done commercially, and I do not see any reason for it, since those metal structures which are most liable to be attacked are iron and they are always massive, and fairly well protect themselves. Lead requires special protection and can be protected by maintaining it negative against ground. I believe a more sensible specification would be not to limit the return drop at all, but to require that the underground metal structures which it is desirable to protect must be made negative and maintained negative against the rail, and then let the railroad company look out for their rails, which would be the only structure in which attack takes place. All the water and gas pipes should be connected to the negative terminal of the dynamo, and maintained negative. That is a complete protection for them.

J. L. R. Hayden (by letter): Confirming Mr. Kintner's statement under 3, I also found that it is necessary to have a duplicate cell for every test, to determine the chemical corrosion. I found, too, that special care must be taken to keep this control cell at the same temperature as the electrolytic cell. A water bath was used in all later tests for this purpose.

My experience does not quite agree with Mr. Kintner's 2, " that the edges of the plates were by far the most active part of the terminals." The plates were usually corroded fairly uniform all over, even on the back, and the edges not more than should be expected from the higher current density existing there.

Mr. Kintner's statement that the current densities assumed by me are very unlikely to exist in actual service conditions, I believe has been fully answered in the discussion by Dr. Steinmetz. Dr. Steinmetz shows that with a cable laid in a duct, and thus partly protected, the current density over the surface of the cable is distributed very unevenly; therefore, fairly high local current densities must be expected.

Regarding the voltage required to produce such current densities, I originally intended to record the voltage per cell also, but found that it was too low to be read accurately with the available voltmeters, in which the scale below 20 volts was not very reliable, and so I had to give it up. Usually from 6 to 8 cells were connected in series with a rheostat, in a 120-volt circuit, and herefrom it follows that the voltage per cell was well within the range of rail-return drop commonly found on American railways. In alternating-current railways at 25 cycles the resistance of the rail return is from 5 to 8 times greater than with direct current, due to unequal current distribution in the rail. The higher trolley voltage permits a higher voltage drop in the circuit, and in this case, even higher rail-return drops may be expected than with direct-current.

Philip Torchio (by letter): Will Mr. Corning please explain how it happened that with feeder districts of alternative signs of potential all the potential-drop readings obtained from water mains were shown on each and all curves all of one sign? One would expect to find negative and positive zones along the water mains traversing the territory, because if the current must practically all flow to the station by the way of trolley wires, this current must at certain points of the water main leave the mains as well as enter them at other points. Were the readings taken at random and the results accidental, or were the points of reading purposely selected?

John W. Corning (by letter): The points at which the readings of potential difference between pipe and rails were taken were so chosen on account of accessibility to pipes at these points without excavation, and the length of line over which conditions were investigated was limited by the number of observers available at the time.

The feeder sections that were supplied with current from the negative pole of the generator to trolley were, as a rule, not the sections farthest from the power stations, but were midway between the inner and outer sections, so that the average condition of potential difference between pipe and rail would not reverse. Had feeder sections farthest from the power station been chosen it is probable that positive potentials on pipes would have been encountered.

A. M. Schoen (by letter): I am much interested in Mr. Knudson's conclusions, drawn from a thirty-day test with current flowing over pipes buried in concrete blocks which were in turn immersed in water. I have never made any detailed laboratory tests of this character, but some years ago while making a general survey in one of our larger cities, for the purpose of determining to what extent water pipes had suffered damage due to electrolytic corrosion, I had an excellent opportunity to note these points in the practical operation of a trolley system. The city was inland, hilly, and well drained, under which conditions the concrete road bed should naturally not be subjected to excessive moisture, the run-off leaving it ordinarily fairly dry. There were in operation in the city two independent overhead trolley systems with track return, one having an 18-in. concrete roadbed, the other having only cross-ties embedded in the soil. The track under which there was no concrete was in many places badly bonded, with resultant heavy leakage to water pipes; after leaving the water pipes much of this stray current found its way back over the better bonded tracks of the line having the concrete roadbed. In many places I found heavy damage done both lead services and cast-iron mains under the tracks of the company using no concrete, while in no single instance, although a large number of excavations were made, did I find damaged even a lead service lying under the concrete. Instances were found where such corrosion had taken place just beyond the edges of the concrete, indicating that this was due to surface leakage. I attribute these results to the fact that the concrete being less porous than the earth, and, owing to good drainage, not continually soaked in water, formed a fairly good insulator and provided considerably protection for the pipes beneath it. With the concrete continually saturated with water, the results would naturally be different.

W. R. C. Corson (by letter): The facts brought out by the experiments recorded in the papers by Messrs. Hayden and Knudson will prove, I believe, valuable additions to engineering knowledge, and while some of the conclusions reached by the writers are probably assailable they serve a valuable purpose in giving direction to new thoughts on an old subject.

My interest has, however, been especially aroused by the paper presented by Mr. Rhodes, and I wish to pay the tribute of appreciation to his ingenious treatment of the subject. The mathematical demonstration of the relative values in the several methods of return feeder distribution is one which will prove of great assistance in the study of the measures to be taken for relief from the effect of stray earth currents.

While I have not had time as yet to follow in detail the various steps through which the demonstration is carried, one conclusion, which seems to be proved and which was touched on but briefly during the discussion, appears worthy of emphasis by repetition; this is, that all methods of return-feeder distribution are more effective in reducing earth currents when the negative bus-bar at the power station is not grounded.

Now the negative feeders from the rail, if run underground in an uninsulated condition, form a more or less perfect ground for the negative bus-bar; and in proportion to the perfection of the ground so formed must reduce the efficiency of the relief from ground currents which they should afford. A corollary to the conclusions of Mr. Rhodes' paper would be therefore that, for efficient relief from earth currents return feeders must be insulated from earth.

It has usually been considered that the measures which a street railway company would naturally take in its own interest to reduce the amount of lost energy on its return system would be effective also in reducing the stray currents on other metallic structures in the streets. Mr. Rhodes' paper clearly shows that the different methods of feeder distribution would not be equally effective for both purposes. For instance, Case II of the paper represents perhaps the most economical method of reinforcing the conductivity of the rail for the purpose of reducing the drop in potential in the return circuit, but this method is shown to be least effective in diminishing earth currents. Again, a single feeder connecting the negative bus-bar to the middle of the track is very effective in reducing earth currents, and, as the effect is independent of the copper in the feeder, an installation of this method might be made without improving in any way the conductivity of the return circuit. The more one studies the question the more forcible is the impression that the street railway's interest and that of other co-occupants of the streets are not equally served by any one measure of improvement.

This conflict of interest has been appreciated by all concerned for many years, although its existence has never been shown so clearly as by Mr. Rhodes' paper. Water and gas associations have received reports from committees appointed to investigate remedies for electrolytic troubles, and these reports have almost invariably demanded changed methods in the construction of street railways, changes which their economical operation prohibited. On the other hand, remedies have been suggested by the electrical interests such as the application of " drainage systems," the insertion of insulating joints in pipe lines etc., which while effective in certain cases, or in certain classes of systems, have been almost universally condemned as unfit by electrical engineers who have under their charge the care of long lines of lead jointed pipe.

It cannot but be a fact that all operating and most consulting engineers have to give the matter of electrolytic corrosion consideration from some point of view. In view of this it appears to me a proper time to suggest that the Institute has an especial opportunity of enlarging its field of usefulness by lending the weight of its authority to a set of recommendations governing the matter of relief from the effects of stray railway currents.

During the discussion, extracts were read from a report made to the American Gas Light Association, which contained the regulations governing the installation of return systems of conductors formulated by a body of German engineers. As I heard these regulations read they appeared for the most part of a reasonable nature, though certain of them were doubtless difficult of attainment. I did not understand, however, from the reading with what authority these engineers acted. If they represented a committee duly appointed by a national non-partisan association of engineers the regulations must have weight in their country and should doubtless prove the basis for "good practice" in installations of the nature covered by them.

In this country no association is so well qualified to take up this matter as our Institute; its membership is representative of the best talent in all fields of electrical engineering; it comprises the men who have been most responsible for the wonderful development of our street railway systems, and whose opinions on the requirements of such systems have become authoritative; it contains also those men who have devoted their abilities to a study of the damage which the railways have done or are doing to underground metallic structures; and men who have for their care the protection of lead-sheathed cables for the conveyance of electrical energy. These men have accumulated from extended experience and study a fund of data and general information on the subject in question, and a committee selected from such a membership would be particularly qualified to examine the whole subject and sift the good and practical from the bad or unwise methods of relief which are in vogue or have been advanced. The recommendations of such a committee modified or amended by a general discussion at an Institute meeting would unquestionably form an authoritative standard of practice which would not only tend to improved conditions of our buried structures. but would redound to the credit of our Institute and increase its prestige.

F. A. C. Perrine (by letter): The results of Mr. Knudson's experiments have been brushed aside by those who have discussed the paper on account, I believe, of a fear that there may be some truth in his statements that will put an additional burden on the street railways of the country. Unfortunately, particularly in reference to the Hamilton Avenue Bridge, Mr. Knudson has drawn some conclusions from his experiments which are probably not warranted by the facts.

I have no doubt but that a current sent through concrete will not only crack it, but will make it soft. In the case of the Hamilton Avenue Bridge, however, there is no evidence from the paper that the concrete was softened, and I understand from the engineer's report on the bridge that the cracking of the concrete was due to settling of the foundations. This is particularly emphasized by the fact that certain building foundations in the same neighborhood have also settled. But I agree with Mr. Knudson's conclusions that blocks of concrete will crack and are made soft by the passage of electric current, because I have had similar experience on quite a large scale with current passed through concrete. In some experiments made about a year ago to determine the efficiency of a large generator, the water rheostat was contained in a concrete basin. After a test lasting about twenty four hours the electrodes were taken from the concrete basin and the water pumped out for the purpose of making some changes in the machinery. Much to the surprise of all concerned, the concrete basin was found to be badly cracked, although during the time of passage of the current from one electrode to another a considerable quantity of water was kept flowing through the basin. The electrodes were three in number, each about four inches in diameter and set about two feet deep in the water, clearing the bottom of the basin by about six inches. The test stopped about 5 o'clock in the morning, and by 8 o'clock in the morning, after the water had been removed from the basin, the concrete was found to be hot and cracked badly, some of the pieces coming out being half as big as a man's body.

The concrete was found to be quite soft, so that it could be whittled like soapstone. This softening ran up along the side of the concrete basin. The damage seemed to have been done by currents passing through the concrete in their path from one electrode to another. I believed at the time, and still believe, that the damage was due to the heating of the concrete as the current passed through it, although this does not quite explain the softening of the concrete itself. In parts where the current must have passed in small amounts the damage to the character of the concrete seemed to be greater than would have resulted from boiling the concrete in water. As was stated earlier in the discussion, enough energy was passed through the concrete by Mr. Knudson to develop an appreciable amount of heat, and if this energy resulted in the dissociation of even a small amount of the water contained in the concrete, the cracks would naturally result. Furthermore, if this water in the concrete so dissociated were water of crystallization, not only would the concrete have been cracked, but it also would have been softened, as described.

I do not believe that there is real danger to buildings on account of this phenomenon, for the simple reason that the conditions for a current passing through concrete to a building frame are not generally present when the concrete is sufficiently wet to afford a ready path for the current; at the same time I have not the slightest doubt but that if the current passed through the concrete the results described by Mr. Knudson would follow, although I question whether the results may properly be called results of electrolysis. I think that this subject is worthy of much more careful study than has been given it. I believe though that such a study will reassure, rather than discourage those owning concrete buildings.

A. A. Knudson (by letter): The tests shown in the paper are the first of the kind attempted by the writer, or by anyone else so far as the writer is aware, consequently the data are confined to what may be termed initial experiments. Had these tests been conducted over a much wider range as suggested, including an analysis of the many brands of cements, and the effect of currents upon each, it is doubtful if there would have been any practical difference in the results. Both the Portland and the Rosendale cements used in the concrete blocks were samples of brands commonly used in building all manner of structures.

The wrought-iron tubes were not turned or polished before being set in the concrete, but were well cleaned.

The weights in the tables are in avoirdupois ounces; all of them were made in the presence of the writer, and on a very delicate scale.

It has been claimed that no proof is presented that the splitting of the concrete blocks was due to electrolytic action. This question seems to have resolved itself into a difference of opinion as to what is proof. In the absence of other reasons for the splitting of the blocks, it may be said that blocks which had current flowing through them were split open, and the block which had no current showed no cracks of any kind, nor the first sign of corrosion upon the tube. The tests were repeated with practically the same results.

Dr. Steinmetz' remarks on this subject confirm my own view of the case. He said:

> It may be electrolytic corrosion of the iron, the formation of oxides which occupy a larger volume and so increase the size of the iron, and cause mechanical destruction by the irresistible force of the increase of the volume which leads to cracking; it may be also electrolytical action resulting in the production of chemical compounds.

Mr. Waterman said:

> Iron incased in concrete is like a battery electrode in a porous cup, so far as insulation is concerned.

Porous cups are not made to adhere to an electrode as is the case of iron in a concrete block. If this were the case they would doubtless crack open in a few hours. It is only where the tests show that a separation from the electrode was caused by the concrete splitting open that there is a similarity. Here probably is the cause of the increase of resistance after the cracks began to show; for as the cracks increased in size, and the concrete separated from the iron, the resistance increased.

In regard to the " restriction " of the flow of current due to a " highly resistant coating " upon the iron; it is pointed out in the paper that electrolytic action had progressed to the point that cracks appeared on the sixth day, and it was not until the ninth day that the rise in resistance really commenced. consequently there could have been no restriction of current flow until *after* considerable corrosion of the iron had taken place and the damage had been done. This test might have been terminated at the ninth or tenth day, so far as establishing the two points are concerned; namely, that concrete is no protection to iron against a current of electricity, and that concrete will be cracked and softened by such current. The voltage, however, was "remorselessly" raised to determine what the final effect would be on blocks in both fresh and salt water. Mr. Waterman said further:

> Just what a corroded water meter had to do with the subject is not clear.

It is distinctly stated in the paper that the two illustrations were placed there as an example of how currents do actually stray into buildings, or piers, and cause damage. Mr. Waterman also said:

> The corrosion of the meters was probably caused by *iron rust*. As a matter of fact the meters were made of bronze, and the currents in each case that caused their destruction were traced from the car tracks.

Referring to Dr. Steinmetz remarks:

> Fortunately iron is a material which is rather stable, and least attacked by electrolytic action. Even wrought iron is not attacked very badly, and steel much less, and cast iron is hardly attacked at all. The problem of protection against electrolysis is not the problem of protecting the rails or gas or water pipes. The underground metal structures which are suffering most are the underground lead cables, and there again it means the telephone cables.

This statement is quite surprising in view of the many instances of pipe destruction which are so generally well known. Even Mr. Corning, representing one of the finest electric railway systems in this country, has stated frankly that they were having a good deal of trouble from electrolysis in one part of their system on the large 48-inch cast-iron mains, and other mains of the Metropolitan Water Works, and they had installed a number of insulating joints in the attempt to prevent electrolytic action.

This is only one illustration from one city of damage by electrolysis to piping systems and other property. This information from Boston was furnished by railroad men. Their statements I can corroborate for I have personally been on the ground and taken measurements in company with others.

Future experimenting with electric currents and steel in concrete will doubtless show further points of interest. The present paper giving the results of experiments is intended as a warning that concrete is no protection to iron or steel when electricity is passing through it.

H. W. Fisher:* Over ten years ago, when the first cases of electrolysis of the lead covering of cables were reported, I made a series of tests to determine the conditions both favoring and preventing electrolytic action on lead-covered cables. As anticipated, I found that only when the lead is positive to ground does injurious electrolysis take place. I also found that electrolysis is not prevented by the addition of 3% tin to the lead, nor by covering the lead with a weatherproof tape or braid saturated with insulating compound. In the latter case, electrolytic action is apt to be concentrated in spots, and thus eat through the lead cover more quickly. For the same reason, I also found that lead-covered cables laid in wooden boxes filled with pitch or bitumen deteriorate rapidly under electrolytic action. As a result of these tests, and others made on cables working under practical conditions, it was found that the amount of electrolytic action depends upon:

1. The proximity of cables to electric railroads.
2. The distance the cables parallel electric railroads.
3. The quality of the electric railroad construction work providing a path for the ground-return current.
4. Numerous other things, including the popularity of the ground return current, the conductivity of the soil, and the position of low soil or water resistance, either along the route of the cables or leading toward the power house, the proximity of the cables to water and gas pipes, the dry or damp condition of the ducts containing the cables, and the chemical constitution of the earth.

From the above data it is evident that the manufacturer of cables cannot guarantee them against electrolysis. He should, however, always be ready and anxious to prescribe such remedies as in his judgment will prevent electrolysis on cables which he has sold. With this end in view, at least one of the cable companies has printed literature dealing with the subject of electrolysis and giving preventive methods and remedies which have proved effective through repeated trials.

The introduction of the single-phase alternating-current railroad system with grounded return brings up the question of electrolysis with alternating currents, and I have been making some experiments to determine whether under any conditions the lead covers of cables may be destroyed by alternating-current. My experiments so far have not been very comprehensive, but I have found that under certain conditions destructive electrolytic action may occur with alternating currents operating at a frequency of 60 cycles.

The solution I employed for the electrolyte was water containing common salt and sal amoniac, all of which may occur in and around duct systems. I found that with a current density of 0.1 ampere per square inch of lead there was no electrolytic action. With 3.04 ampere per square inch of surface, the amount of lead destroyed per ampere per hour per square inch was 0.004 grammes. With 11.8 ampere per square inch, the amount of lead destroyed per ampere-hour per square inch was 0.136 grammes. With 17.9 ampere per square inch, the amount of lead destroyed per ampere-hour per square inch was 0.237 grammes. In this last case, a large hole was eaten through the lead and the surface exposed to electrolytic action was nearly one square inch. These tests were made without any attempt at great accuracy. The results show very plainly, however, that if the current density per square inch of surface is sufficiently great destructive electrolytic action can take place with alternating currents.

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*Presented originally at a meeting of the Pittsburg Branch, December 12, 1905.

Thinking that the action might be due to the large amount of energy dissipated over a small area, I repeated the experiments with direct-current of slightly larger density per square inch, applying the negative side to the lead cover. No lead was destroyed. It may be possible that with other ingredients in the soil or ducts the alternating-current action may be greater than that here given. While in many cases the current density per square inch of surface may not be sufficiently great to cause destructive action on the lead covers of cables, yet while there is a possibility of such action occurring, the cable companies cannot guarantee their cables against electrolysis from alternating currents.

The apparent remedy is to make the difference of potential between the lead cover and ground so small that the current density per square inch of surface is not sufficiently great to cause destructive action. This may be accomplished in different ways, depending on local conditions. With a frequency of 25 cycles, the alternating-current action would probably be greater than that shown by my tests.

R. A. L. Snyder: The name telephone cable is inseparably connected with the subject of electrolysis. No underground construction has suffered from the ravages of electrolytic corrosion quite so severely as the telephone cable. Our company's experience with this subtle destroyer has been a very sad one. In the early days of telephony we installed a large underground cable plant, and this plant, which cost us $150,000, was entirely destroyed by electrolysis. The plant was known as the " solid system " in distinction from our later plant, now in use, known as the " drawing-in-system."

The solid system was very carefully laid in order to prevent electrolysis. A wooden box was installed and the cables laid in the box on a layer of mineral pitch. The box was then filled with the pitch so as completely to surround the cables. A layer of pitch at least one inch thick separated the cables from the box on every side. Another precaution was taken, by attaching grounding plates to some of the cables at regular intervals; but with all this elaborate protection electrolysis destroyed the system.

At first very little trouble was experienced, for the reason that the electric roads did not become prevalent until about 1894. Before this time Pittsburg's longest street car line was a cable road. During 1896–7 our troubles increased rapidly, but thanks to the new drawing-in-system which we had started in 1893 we were able to replace the solid system very rapidly.

When one of these solid-system cables would show trouble, we had to locate it as closely as possible and then dig up the streets. This was a very expensive operation, especially when the trouble occurred in two places, which meant that we were obliged to open the street for a distance of three or four hundred feet. When the cable was uncovered, the sheathing would be found pitted in many places. Our first solid-system cables laid to the East End exchange had to be abandoned after operating only a few years.

So much for the solid system. The next problem after getting our cables installed in the new system was how to prevent them going the way of the old cables. The electric roads were increasing the size of their plants and the leakage of current was becoming greater. It was generally conceded that the best plan was to make the cables negative to earth as in the old system, as it was noticed that corrosion generally took place where the cables were positive to earth; but there were records showing that cables strongly negative to earth often generated chemicals which reacted to destroy the lead sheathing. This was especially true where the current was shut off during the night.

Some years ago a mass of slimy matter was taken from beneath the electric car rails on Boylston Street, Boston, and sent to the Massachusetts Institute of Technology to be examined, where it was found to consist mostly of sodium hydrate with particles of metallic sodium distributed through it. These particles of sodium burst into flame when thrown into water. Sodium chloride or common salt was used to melt the ice along the rails. This may have been turned into sodium when acted upon by currents flowing into the rail.

As the law at this time apparently furnished no protection to our property from the traction company's stray currents, we decided to go to the expense of running long bond wires to the negative poles of their generators, thus making the cables negative to earth. The result of this course has been very satisfactory compared with our former experience, but we have still had our troubles. At times our cables would carry so much current that they would arc to well-grounded conductors, burning holes through the cable sheathing. At Twenty-first Street and Spring Alley the arcing was severe enough to set fire to a terminal pole and required the services of the fire department to extinguish the flames. In the neighborhood of Twentieth

Street, we had a number of cable terminals burnt where they passed through the pole pipes. This trouble became so bad that in several places we insulated the cable terminal from the pipes with rubber hose.

Several years ago, we had our cable system bonded to the traction company's negative return on Twentieth Street with three No. 0 copper wires. These wires carried enough current to heat them to a temperature of 212° fahr. About this time we noticed a change in the electrolytic condition of our cables and upon investigation found that the wires were burned off a short distance from the manhole.

In some cases where our cables are positive to ground at distant points from the power houses we have allowed them to eat away rather than to go the expense of running a bond wire. Our record of losses from electrolytic corrosion for the past few years is as follows:

1901—One case
1902—Two cases
1903—Two cases
1904—Two cases
1905—Seven cases.

Our troubles appear to be increasing, yet we have spent more money running bond wires during the past year than ever before, despite the fact that the traction company have electrically welded their rails. We have done everything known to the art to prevent electrolytic corrosion of our cable.

The drop in potential between our Grant office building and the cable sheathing at Twentieth Street and Spring Alley is often over twenty volts. Sometime ago we had some spare cable conductors grounded to the cable sheathing at Twentieth Street and the current was used in our laboratory to run a small motor. There was enough current to light a 50-candle power 50-volt lamp to a bright red.

The anchors holding our aerial cables have also suffered from electrolytic corrosion. They have to be made negative to ground by running bond wires. This occurs in almost every town in our territory, and when an anchor breaks the cables fall to the ground, causing a big repair bill.

For a long time the Ben Venue power house was run only for a few hours each day. In this neighborhood we had much trouble from the continually changing conditions. I understand that the Pennsylvania Railroad had to replace their signal air-pipes in this neighborhood several times.

In conclusion, I would say that our present policy is to maintain all parts of the cable system free from electrical contact with underground steel and iron structures; to keep the parts well bonded together, and most of all to have them slightly negative to earth. I would advise all owners of underground metal construction to do likewise until the traction company adopt some method of carrying return currents in their own conductors.

To be delivered at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25, 1907.

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THE PROPERTIES OF ELECTRONS

Presidential Address

BY SAMUEL SHELDON

Introductory. The physical properties of electrons form the basis of electrical engineering, and a thorough understanding of them is essential for successful investigation in some departments of research. No specific treatment of the subject has appeared in the printed publications of the Institute. It is therefore hoped that what follows will be of service to the membership. No attempt has been made to treat of the conduction of electricity through gases, of the phenomena of radioactivity, nor of electrolytic conduction, in all of which the electron plays an important part.

The Electron. Electrons, which are called corpuscles by some physicists, are the smallest particles of matter that have been isolated. They are considered by some (Larmor) to be constituted of ether. Their shape is unknown, but it is frequently assumed as spherical. At ordinary velocities the mass of an electron is 6.3 10^{-28} grams; at rest, its mass may be zero; and at velocities approaching closely to that of light it becomes nearly infinite. Each electron carries an invariable negative electric charge of 1.1 10^{-19} $[=e]$ coulombs, = 1.1 10^{-20} $[=e_m]$ electromagnetic units, = 3.4 10^{-10} $[=e_s]$ electrostatic units. Some writers use the term to designate as well particles carrying positive charges and having other properties. Such use is not common nor desirable.

Electrons in a free condition are present in metallic conductors, in gases, especially at low pressures, and to a limited degree in ordinary solid dielectrics. They are not present in free ether or space. Combined with other electrons and with an unknown something or condition, that gives under certain conditions evidences of positive electrification, electrons are present in all matter. Their properties are in nowise dependent upon the properties of the matter with which they are associated; and they are considered to be indestructible by any agent within the command of man. Every electron is in some manner entangled with the luminiferous ether.

The ether is a fluid plenum or continuum, endowed with the properties of inertia and rotational elasticity, and is the medium through which all forces are exerted. It fills all space between electrons and the bounds of the universe; it is supposed by some to penetrate the electrons, and (Lorentz) remains stagnant during the passage of electrons through it.

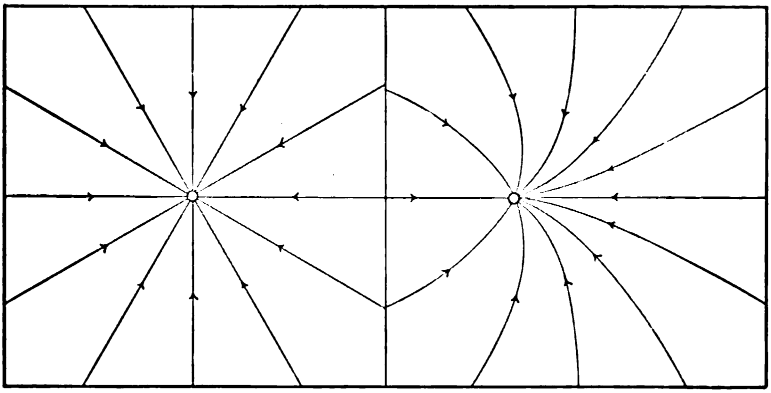
Stationary. Moving to the left.

FIG. 1.—Distribution of electric flux from an electron.

Each electron, when isolated and at rest, produces at every point in the ether an elementary electrostatic field. corresponding in direction and intensity to its charge. All electrostatic fields are due to the resultant superpositions of such elementary fields. The force exerted upon an electron in a field of intensity E, produced by a plurality of electrons, is Ee_s dynes, both quantities being expressed in electrostatic units. An electron moving with uniform velocity in a straight line at a velocity v cm/sec produces at every point both an electric field and a magnetic field, and carries them with it. If the motion be in the direction of the Z axis of coördinates, and the velocity be small as compared with that of the propagation of ether disturbances, at a point whose coördinates are x, y, z, the electric field will be radially directed, and have a magnitude E, in electrostatic units, the same as when at rest. With the electron at the origin and with a medium of unit permeability, the equation for E is

$$E = \frac{e_s}{4\pi} \frac{1}{(x^2+y^2+z^2)}; \tag{1}$$

and the intensity components α, β, γ, of the magnetic field parallel to the X, Y, and Z axes, respectively, are given by the equations:[1]

$$\begin{aligned} \alpha &= e_m v \frac{y}{(x^2+y^2+z^2)^{\frac{3}{2}}} \\ \beta &= -e_m v \frac{x}{(x^2+y^2+z^2)^{\frac{3}{2}}} \\ \gamma &= 0 \end{aligned} \tag{2}$$

For large velocities, the velocity of light being c cm/sec,

$$\begin{aligned} E &= \frac{e_s}{4\pi} \frac{c}{(c^2-v^2)^{\frac{1}{2}}} \left\{ \frac{x^2+y^2+z^2}{\left(x^2+y^2+\frac{c^2}{c^2-v^2}z^2\right)^3} \right\}^{\frac{1}{2}} \\ \alpha &= \frac{e_m c v}{(c^2-v^2)^{\frac{1}{2}}} \frac{y}{\left(x^2+y^2+\frac{c^2}{c^2-v^2}z^2\right)^{\frac{3}{2}}} \\ \beta &= \frac{e_m c v}{(c^2-v^2)^{\frac{1}{2}}} \frac{x}{\left(x^2+y^2+\frac{c^2}{c^2-v^2}z^2\right)^{\frac{3}{2}}} \\ \gamma &= 0 \end{aligned} \tag{3}$$

An electron, with its charge e_m, moving with uniform velocity v cm/sec at an angle θ to the direction of a magnetic field of intensity H, is acted upon by the field with a force whose magnitude is

$$F = H e_m v \sin\theta \text{ dynes.} \tag{4}$$

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[1] Heaviside, Phil. Mag., p. 324, April, 1889; J. J. Thomson, Cond. of Elect. Through Gases, p. 531.

If an electron, moving with a velocity small compared with c cm/sec that of light, suffer a change either in the magnitude of its velocity or in its direction, a radiation of energy between it and the surrounding ether will take place whose magnitude is[2]

$$J = \tfrac{2}{3}\,\frac{e_m{}^2\,a^2}{c}\ \text{erg/sec}, \tag{5}$$

where a is the acceleration in cm/sec.[2]

Charge of the Electron. J. J. Thomson[3] and others have determined the magnitude of the charge carried by a negative gaseous ion, which is the same as that carried by an electron. The method employed for measuring the charge depends upon the discovery[4] that if a dust-free ionized gas, saturated with water vapor, be adiabatically expanded so that the ultimate volume bears to the initial volume a ratio of 1.25, droplets of water will form about the negative ions, but condensation will not occur around the positive ions until this ratio reaches the value 1.31 when droplets will form about both ions. Using an expansion of ratio 1.25, the charge on a negative ion can be found from a determination of the number of droplets and of the total charge on all the droplets. The number of droplets is obtained from a determination of the size of each droplet and the weight of all of them. The total weight can be obtained from the known properties of gases that are saturated with water vapor.

The size of the droplets can be obtained from the rate at which the cloud, that they form in the enclosing receiver, settles. According to Stokes' law, the terminal velocity u cm/sec of a sphere of radius r cm and excess of density d, falling through a gas of which the coefficient of viscosity is η, is expressed by the equation

$$u = \frac{2}{9}\,\frac{d\,g\,r^2}{\eta},$$

whence

$$r = \sqrt{\frac{9\,\eta\,u}{2\,g\,d}}, \tag{6}$$

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[2] Larmor, Æther and Matter, p. 227; Phil. Mag., Dec., 1897, p. 512.

[3] J. J. Thomson, Phil. Mag., 1898, Dec., 1899, Dec.

[4] C. T. R. Wilson, Phil. Trans., A., 1897, p. 265.

g cm/sec^2 being the acceleration due to gravity. From observation of u and a determination of η the value of r is obtained.

The droplets upon falling are allowed to collect in an insulated receptacle connected with an electrometer. H. A. Wilson[5] checked the determination of the size of the droplets by observing their rate of movement in a strong electric field arranged to act against or with gravity.

The total charge was determined by Thomson by impressing a small potential difference v volts upon two parallel horizontal electrodes so placed as to include between them all the ionized gas, and by measuring the current-density I ampere/cm^2 which flowed through the gas. Let N = total number of ions per cubic cm, positive as well as negative, e = charge on each ion in coulombs, u' = sum of velocities under a gradient of 1 volt/cm, of positive and negative ions (determined by a special method),.and l the distance between the electrodes, then the charge on each ion is

$$e = \frac{l\, i}{N\, u'\, V} \text{ coulombs.} \tag{7}$$

Thomson's latest value for e_s is 3.4 $10^{\cdot 10}$, using an expansion ratio of 1.31 and thereby obtaining the total number of positive and negative ions.

Mass of the Electron. Many determinations of the ratio of the charge on an electron to its mass m have been made, from which, knowing the charge, the mass can be obtained. One method, used by Thomson, was to pass a stream of electrons, projected from a cathode in a highly exhausted tube, through a magnetic field of uniform intensity H and perpendicular in direction to the path of the electrons. If the electrons be moving with a velocity v cm/sec, the field will exert a force $e_m\, v\, H$ dynes upon them, and they will move in a circular path, whose radius can be determined from the observed deflection of the stream; and has a value, as in any case of centripetal acceleration, of

$$r = \frac{m\, v}{e_m\, H} \text{ cm,}$$

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[5] H. A. Wilson, Phil. Mag., April, 1903.

whence $$m = \frac{r\, e_m\, H}{v} \text{ grams.} \tag{8}$$

To obtain v the electrons must simultaneously be subjected to the influence of an electric field of intensity E in electrostatic units, whose direction is perpendicular to the lines of force of the magnetic field and also to the original path of the electrons. By adjusting the intensity and sign of the electric field until the force it exerts upon each electron $E\, e_s$ is equal and opposite to that exerted by the magnetic field, it follows that

$$E\, e_s = H\, e_m\, v, \tag{9}$$

or $$v = \frac{E\, e_s}{H\, e_m}.$$

And $$m = \frac{r\, e_m\, H^2}{E}\ \frac{e_m}{e_s} \text{ grams.} \tag{10}$$

Another method of obtaining an expression for v, involving m and measurable quantities, used by Thomson, was to allow the electrons to bombard the face of a thermopile whose rate of increase of temperature could be determined from the rate of increase of the thermoelectromotive force. If the face of the thermopile be bombarded by N electrons per second, moving with a velocity v cm/sec, heat will be communicated to it at such a rate dk/dt that

$$\mathbf{K} = dk/dt = \tfrac{1}{2}\, N\, m\, v^2. \tag{11}$$

If the charges of the electrons be allowed to pass to an insulated conducting system connected with an electrometer, the rate of increase of negative charge can be obtained, and is

$$\mathbf{e} = de/dt = N\, e.$$

Therefore $$v = \sqrt{\frac{2\, e\, \mathbf{K}}{m\, \mathbf{e}}}, \tag{12}$$

and $$m = \frac{r^2\, e\, H^2\, \mathbf{e}}{2\, \mathbf{K}}. \tag{13}$$

Another method of obtaining an expression for v, used by Kaufmann[6] and by Simon,[7] is based upon the assumption that all the kinetic energy of the electrons is represented by the energy that would be required to transfer their charges between two points having a difference of potential V equal to that existing between the cathode and the anode of the containing tube.

In this case

$$\tfrac{1}{2} N m v^2 = V N e, \tag{14}$$

and substituting the value of v in (8),

$$m = \frac{r^2 e H^2}{2V}. \tag{15}$$

This method gives too large values because it does not take account of the energy lost in collisions, and that required to detach the electron from the cathode.

Many other methods of determining m have been employed: all yielding values of the same order of magnitude, but differing considerably from one another. The first determination of the ratio e_m/m was made by Zeeman in connection with his experiments on the influence of the magnetic field upon the spectra of gases. The values obtained by various methods, and upon electrons obtained in various ways are given in the following table[8] from Lorentz:

Method.	$\frac{e_m}{m} 10^{-7}$	v/c
Zeeman effect	1.6 to 3	0.1 to 0.3
Rotation of plane of polarized light	0.9 to 1.8	
Cathode rays (Simon)	1.86	
Cathode rays (other observers)	0.7 to 1.4	
Ultra violet rays on zinc	0.7	
Radium β rays	1.75	Small.

The differences between the values obtained are probably due to some of the electrons being loaded with matter, and to the various velocities with which they were moving.

The influence of velocity upon mass has been determined by Kaufmann in the case of electrons ejected from radium preparations in the form of β rays.

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[6] Kaufmann, Wied. Ann., 61, p. 544; 62, p. 596; 65, p. 431.

[7] Simon, Wied. Ann., 69, p. 589.

[8] Lorentz, Electrotechnische Zeits., June 15, 1905, p. 558.

Suppose a charged electron to be moving in a curved path, and to be accelerating both tangentially and radially. Let the tangential acceleration be a_1 and the radial be a_2. Inasmuch as a moving electron produces a magnetic field, whose lines are circular and lie in a plane perpendicular to the direction of motion, and whose intensity at any point is proportional to the velocity of the electron, the acceleration must be accompanied by an increasing strength of field. As this increase requires that work be performed upon the ether, part of the force which causes the acceleration must be used in performing this work.

Let m_1 and m_2 represent two coefficients, which, when multiplied, respectively, by the accelerations a_1 and a_2 give the forces required to perform this work represented by the increasing intensity of the two components of the magnetic field. Then if m_0 be the mass as ordinarily understood, of the electron, the tangential and radial components of the force, respectively, will be

$$\left.\begin{aligned} f_t &= a_1\,(m_0+m_1) \\ f_r &= a_2\,(m_0+m_2) \end{aligned}\right\}\text{ dynes} \tag{16}$$

The coefficients m_1 and m_2 appear, therefore, to represent, respectively, longitudinal and transverse electromagnetic masses of the electrons, which it is assumed has also a true mass m_0.

Now m_1 and m_2 are not constant, but depend upon the velocity of the electron, as shown in equations (2), (3) and (5). For small velocities, as compared with that of light, if the electron be assumed as spherical of radius R cm and with its charge e_m spread uniformly over its surface, m_1 and m_2 each have the value;[9]

$$m_1 = m_2 = \frac{2}{3}\,\frac{e^2_m}{R} \tag{17}$$

For greater velocities these values increase, until at the velocity of light they become infinite. Using analytical results obtained by Abraham, Kaufmann concludes from his experiments upon the deflection of β rays that, within the limits of experimental errors, (m_0+m_2) varies with the velocity as m_2 should, and therefore $m_0 = 0$, that is, a stationary electron has no mass whatsoever, and all the mass of a moving electron is due to its entanglement with the ether. The values determined by Kaufmann and the percentage difference from theoretical values based upon the assumption $m_0 = 0$ are given in the following table:[10]

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[9] Thomson, Recent Researches in El. and Mag. 1893, p. 21.

v/c	m_2/m Observed	Per cent. variation from theoretical
Small	1.	——
0.732	1.34	−1.5
0.752	1.37	−0.9
0.777	1.42	−0.6
0.801	1.47	+0.5
0.830	1.545	+0.5
0.860	1.65	0.
0.883	1.73	+2.8
0.933	2.05	−7.8 (?)
0.949	2.145	−1.2
0.963	2.42	+0.4

The following curve shows the relation which exists between the mass of an electron, expressed in terms of its mass at low speeds, and its velocity, expressed in terms of that of light.

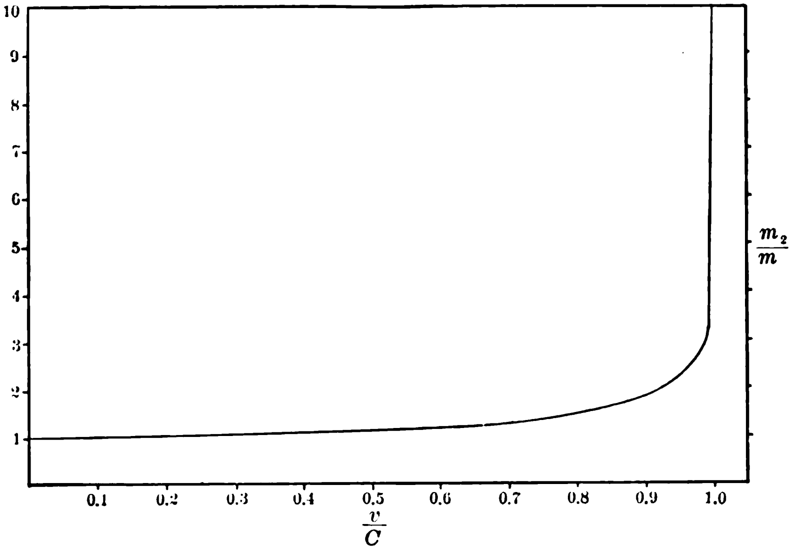

FIG. 2.

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[10] Rutherford, Radio-Activity, p. 111.

The mass at small velocities is $6.3\ 10^{-28}$ grams. At a velocity equal to that of light, the magnetic flux, surrounding an electron in a plane perpendicular to its path and passing through it, should become infinite. This follows from the substitution of $v=c$ and $z=0$ in equations (3). The electron thereby would acquire an infinite self-inductance. Consequently an infinite force would need to be exerted upon it in order to produce a finite acceleration. The mass of the electron, therefore, at this hypothetical velocity, would be infinitely large.

Size of the Electron. If it be assumed that the electron is spherical in shape, then knowing its charge e_m, and its apparent mass at low speeds m_1, its radius R can be obtained from equation (17)

$$R = \frac{2}{3} \frac{e^2{}_m}{m_1} = 1.3\ 10^{-13}\,\text{cm}, \tag{18}$$

which is much smaller than the diameter of atoms. Lorentz has been led to conclude, from the consideration of various phenomena appearing in moving systems of different kinds, that the electron is spherical when at rest, ellipsoidal at intermediate speeds, and a flat disc at the speed of light. Upon this assumption he obtains results, after a severe and complicated mathematical analysis, that are in accord with Kaufmann's experimental results; give larger masses for the same speed than those obtained by Abraham; give a mass of zero at rest, and are consistent with equation (17).

The Atom. On the supposition that the atom consists of a sphere of uniform positive electrification in which are contained a number of moving electrons, Thomson,[11] in 1904, endeavored to determine how electrons would arrange themselves in various atoms, and what properties would thereby be conferred upon the latter. Mathematical difficulties prevented a general solution for a spherical arrangement, but a solution for arrangements in rings was obtained, which has, by analogy, been applied to the spherical arrangement.

According to these results it has been assumed that the atom consists of negatively charged electrons uniformly distributed over concentric spheres, as a result of their mutual repulsion, and enclosed in a sphere of uniform positive electrification of such intensity that the electric field that would be produced outside the atom by the charges on the electrons is nullified.

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[11] J. J. Thomson, Phil. Mag., March, 1904, p. 237.

Examination of the distribution, necessary for equilibrium, of such aggregates consisting of consecutive numbers of electrons, reveals the following facts:

1. The distribution of one aggregate may differ from that of another in having a greater number of electrons distributed upon one or more additional concentric shells. The first aggregate has as a nucleus the identical distribution of the second.
2. The equilibrium of the distributions of some aggregates may be very stable, while that of others is less so.
3. Some less stable aggregates will become more stable if one or a few electrons be added to it, thereby giving the atom which it represents a negative resultant charge.
4. Some less stable aggregates will become more stable if one or a few electrons be taken away from it, thereby giving the atom which it represents a positive resultant charge.

Assuming the atoms of the various chemical elements to be thus constituted, the equilibrium requirements will explain their physical and chemical differences and similarities. The different aggregates indicated in (1) would yield atoms of similar qualities, but different atomic weights, as lithium, sodium and potassium. If an atom, consisting of an aggregate whose equilibrium would be rendered more stable by the losing of one electron, should be brought up to an atom requiring for stability an additional electron, a transfer of one electron would account for known facts. The first atom would afterwards have a resultant positive charge. The second atom would have a resultant negative charge, and the two would attract each other. The first atom would correspond to an electropositive atom, like that of sodium, and the second atom would be electro-negative like chlorine. After the change and resulting attraction a molecule of sodium chloride is formed. Chemical affinity is thus considered to be due to electric attractions.

The number of electrons in an atom may vary from time to time, and the atom may therefore have a positive or negative electrification or may be neutral. The combination of two or more atoms, that are held together by electric attractions resulting from differences in the sign of their electrifications, constitute a molecule. The atoms may be of the same or different chemical elements.

If stable equilibrium is obtained by the loss of one and only one electron the aggregate gives an atom that is univalent and electro-positive; if a single additional electron is required for stability the atom is univalent and electro-negative. The requirement of a loss or gain of two, three or four electrons for complete stability characterizes the atoms as divalent, trivalent, and quadrivalent respectively.

More complex molecules, as for instance the various oxides of lead, result in some cases in an incomplete stability of the component atomic aggregates.

The electrons in the atom are supposed to be moving continuously in orbits, subject to displacement and distortion under certain circumstances. The large number of electrons and their entanglement with the ether has been offered as an explanation of the spectra characteristic of different substances, which are in some cases very complex.

Some aggregates are stable when the electrons move in their orbits with an angular velocity greater than a certain value; and they become unstable when the velocity falls below this value. Electron velocities decrease very slowly as a result of the loss of energy which they radiate. When, however, the critical velocity is reached, an entirely new distribution may take place, and may be accompanied by ejection of some electrons from the atom. This is possibly what takes place in the case of radium.

As a consequence of the results obtained by Thomson,[12] in 1904, concerning the structure of the atom, many have concluded that an atom of hydrogen contains over a thousand electrons and that its mass is equal to the sum of the masses of the electrons. It, therefore, has no true mass, but merely an electromagnetic mass. They have also concluded that atoms of other atomic weight contain a proportionally larger number of electrons. Such an atomic structure would satisfactorily explain differences in the atomic weights and might lead to some conclusions explanatory of characteristic spectral complexities. Thomson, however, has more recently[13] concluded from experiments upon the dispersion of light in gases, upon the scattering of Röntgen radiation in gases, and upon the absorption of β rays from radium compounds that " The number of corpuscles (electrons) is not greatly different from their atomic weight." He finds from the dispersion due to hydrogen that a hydrogen atom contains not far from one electron and that the mass of the carrier of positive electrical charge is large compared with that of the electron. From the scattering of Röntgen radiation in air he calculates that there are 25 electrons in a molecule of air.

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[12] Thomson, Phil. Mag., Vol. 7, No. 39, p. 237-265, March, 1904.

[13] Phil. Mag., p. 769, May, 1906.

The Ion. An important part is played in the phenomena of electrophysics by atomic aggregates of electrons that exhibit an external electrical field. When an aggregate or system of aggregates with an excess of positive or negative electrification is subjected to the influence of an auxiliary electric field it tends to move in the same or opposite direction to that of the lines of force of this auxiliary field, according to the sign of its excess of electrification. It may then be termed an ion, positive or negative according to the sign of its excess of electrification. In the various physical states of matter are present the following:

NEGATIVE IONS

1. Isolated and free electrons.
2. One or more electrons acting as a nucleus for a cluster of molecules, the cluster roughly estimated, in some cases, as containing 30 molecules.
3. Atoms of electro-negative elements the instability of whose aggregate has been reduced by the addition of one or more electrons.

POSITIVE IONS

1. Atoms of electro-positive elements the instability of whose aggregate has been reduced by the subtraction of one or more electrons.
2. Molecular clusters from which an electron has been removed.

Negative ions may or may not be associated with ordinary matter. Positive ions are always found associated with it.

The lines of force of the electric field of an isolated ion are directed radially towards it as a center. In a molecule, while practically all the lines of force start from its electro-positive atoms and terminate upon its electro-negative atoms, thus being electrostatically nearly saturated, the field distribution is different for different planes passed through its molecular center. The molecule does not, therefore, suffer translation when placed in an auxiliary electric field, but rotates and orients itself. The orientation of a system of molecules produces a polarization of the substance containing the system.

Free electrons exist in gases at pressures under 10 mm. of mercury, especially when subjected to ionizing agencies; in conducting solids; in the β rays from radium; and in conducting flames.

Clusters exist in all conducting gases under pressures greater than 10 mm. of mercury; sometimes in gases at lower pressures, and possibly in liquids and solids.

Electronized or deelectronized atoms or both, exist in all conducting gases at all pressures; both exist in liquid electrolytes; in solid conductors, and possibly in solid dielectrics.

The Production of Ions, or Ionization. In all gases at ordinary atmospheric pressures spontaneous ionization is continually going on. This doubtless results from molecular collisions of an intensity much above the average. Recombination of positive and negative ions is also continually going on and will be discussed later. If an ionized gas of volume V cm^3 be enclosed in a receiver provided with two electrodes connected to the terminals of a source of electromotive force, an electric current can be made to flow through the gas and circuit. Under the influence of the electric field set up between the electrodes, the negative ions move towards the anode and the positive ions towards the cathode. A negative ion upon reaching the anode gives up to it an electron with its charge of 1.1×10^{-19} coulombs. The ion thus becomes transformed into an ordinary atom. What the anode does with the electron need not concern us at this point. In a like manner the positive ion upon reaching the cathode receives from it an electron and itself becomes an ordinary atom. The double exchange is accompanied by what is generally understood as the conduction of $1.1\ 10^{-19}$ coulombs through the gas. It is also accompanied by the disappearance from the gas of one positive and one negative ion. If an increased voltage be employed, the velocity of the ions will increase, the current or rate of transference of electric quantity will increase, and the rate of disappearance will increase. The last can never be made to exceed the rate of production of ions. Therefore, a limiting saturation current is reached, which cannot be exceeded even though the voltage impressed upon the electrodes be increased, so long as this increase does not, of itself, produce ionization. Spontaneous ionization of gases at ordinary atmospheric pressure will permit the passage of only about $3.3\ 10^{-18}$ amperes per cubic centimetre.[14]

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[14] Wilson, Proc. Camb. Phil. Soc. x; p. 32, 1900; Proc. Roy Soc. lxviii, p. 151, 1901.

Recombination of ions occurs in gases at a rate proportional to the square of the number present. If N ions per cm^3 be present at a given time, then the number n present after t seconds will be

$$n = \frac{N}{N\,\alpha t + 1} \tag{19}$$

where α is a coefficient of recombination, which equals[15] $1.1\ 10^{-6}$, and has the same value for hydrogen, carbon dioxide, air, and probably other gases. Its value is independent of pressures above $\frac{1}{8}$ atmospheric, but decreases with decrease of pressures below this limit.

It has been determined by Townsend that an electron, moving in a rarefied gas along a free path whose terminal points differ in potential from each other by 20 volts, *i.e.*, 20/300 electrostatic units, acquires just sufficient energy to ionize a molecule with which it comes into collision. The energy required for the production of one negative and one positive ion from a gas molecule is therefore equal to the product of this potential drop by the charge on the electron, that is,

$$\frac{20}{300}\ 3.4\ 10^{-10} = 2.3\ 10^{-11} \text{ ergs.}$$

The velocity v acquired by the electron of mass m just before collision, is derived from the equation of energy $\frac{1}{2}\,m\,v^2 = 2.3\ 10^{-11}$, and is

$$v = \sqrt{\frac{4.6\ 10^{-11}}{m}} = 2.7\ 10^{8} \text{ cm/sec.} \tag{20}$$

This velocity is very great as compared with the mean molecular velocity of gases at ordinary temperatures. In weak electric fields the electrons or negative ions, but not the positive ions, produce fresh ions by collision. In strong fields both negative and positive ions produce them.

Salts introduced into the flame of a Bunsen burner are ionized and the flame becomes conducting. Hot metals ionize the gas in contact with them and eject negative ions from themselves. A temperature of 200° cent. is sufficient to produce some ionization. Platinum[16] at 1500° cent. in a vacuum permits a maximum current towards it, by means of negative electrons which it throws off, amounting to one milliampere per square centimetre. Heated carbon filaments have been found to supply sufficient ions to allow of one ampere per square centimetre of surface.

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[15] Townsend, Phil. Trans. A., 193, p. 129, 1900.

Gaseous ions are also produced as a result of energy expended by radioactive substances, as by X-rays, by Lenard rays, by ultraviolet light, and likewise by chemical action.

Metallic Conduction of Electricity. Investigations concerning the nature of the process of electric conduction in metals have led to the conclusion that in the metals are to be found molecules and atoms of the metallic element, positive ions, and free electrons. The molecules and atoms are not free to migrate from one part of the metal to another, but have a limited freedom of movement about a mean position. The electrons are not constrained to any particular part of the metal, but are free to move from one part to another, such movement being accompanied by collisions and changes in the direction of movement, in a manner similar to that accompanying the movement of molecules in a gas, considered from the standpoint of the kinetic theory of gases. The positive ions have been supposed by some to change their positions, by others not. The number of free electrons per cubic centimetre of metal is very large, being of the order of a billion billions. The mean free path of an electron scarcely exceeds one millionth of a centimetre in any case. The number per cubic centimetre and the length of free path is different with different metals. In an ordinary metal at a uniform absolute temperature of T degrees, all the particles of the metal are in motion, collisions are constantly occurring, and the directions of the motion are such as result from chance. According to the doctrine of the equipartition of energy, the mean kinetic energies of the molecules, of the atoms, of the positive ions, and of the electrons, are equal to each other and dependent upon the absolute temperature. Inasmuch as the masses of the electrons are much smaller than those of the other particles, the velocities of the electrons must be much greater.

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[16] O. W. Richardson, Proc. Camb. Phil. Soc., xi, p. 286, 1902.

Following Drude,[17] assume a metallic conductor of unit cross-section, and length L cm's., containing N electrons per cubic cm. each of mass m and with a charge of e_s electrostatic units. If a difference of potential V in electrostatic measure be established between the ends of the conductor, the electrons will be subjected to the influence of an electric field of intensity $E = V/L$ and, during the interval of time τ between collisions, they will be subjected to a force in the direction of the length of the conductor such that

$$m \frac{d^2 L}{d \tau^2} = E e_s \text{ dynes.} \tag{21}$$

Integrating throughout the time τ and evaluating constants,

$$m L = \tfrac{1}{2} e_s E \tau^2. \tag{22}$$

The electrons, if the difference of potential be maintained, will in addition to their original undetermined velocities have a velocity component v_L in the direction of L such that

$$v_L = \tfrac{1}{2} e_s E \frac{\tau}{m} \tag{23}$$

A quantity of electricity will pass per second through a cross-section of the conductor, which constitutes a current I_S in electrostatic units, such that

$$I_s = e_s N v_L = \tfrac{1}{2} e_s^2 N \frac{\tau}{m} E = \tfrac{1}{2} e_s^2 N \frac{\tau}{m} \frac{V}{L} \tag{24}$$

The resistance per unit length, that is the resistivity of the metal, will, in electrostatic units, be

$$\rho = \frac{V}{L I_s} = 2 \frac{m}{e_s^2 N \tau} \tag{25}$$

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[17] Drude, Trans. Int. El. Cong., 1904, Vol. 1, p. 319.

The specific electric conductivity will equal the reciprocal of the expression or

$$\sigma = \tfrac{1}{2}\, e_s^2\, N \frac{\tau}{m} \tag{26}$$

It is desirable to substitute for τ another expression, which takes into account the mean velocity, v, of the electron in the direction of its path and the average length λ of its free path. Since $v\,\tau = \lambda$,

$$\sigma = \tfrac{1}{2}\, e_s^2\, N \frac{\lambda}{v\,m}. \tag{27}$$

Metallic Conduction of Heat. It is probable that the flow of heat in metal under maintained difference of temperature is due to the presence of electrons in the metal, they acting as carriers and distributors of energy which they possess in the kinetic form. According to the kinetic theory of gases every molecule or particle possesses an average kinetic energy h at an absolute temperature of T such that

$$h = \alpha\, T, \tag{28}$$

where α is a universal constant, which has a value of $1.6\ 10^{-16}$ ergs per absolute degree. If metals be ultimately constituted as has been assumed, then an electron, when uninfluenced by electric or magnetic forces, has the same energy as a gas molecule at the same temperature.

From the kinetic theory of gases, an expression for the heat conductivity of the metallic conductor, considered above, may be obtained. If one end of it be heated, the flow of energy or heat Q per second in the direction of its length and across any transverse cross-section of the conductor is given[18] by the equation

$$Q = \frac{v\,\lambda\,N}{3}\ \frac{d\,h}{d\,L}\ \text{erg/sec.} \tag{29}$$

Substituting the value of h from (28),

$$Q = \tfrac{1}{3}\,\alpha\, v\,\lambda\, N \frac{d\,T}{d\,L}. \tag{30}$$

The heat conductivity k of the metal in mechanical units, that is, in ergs per square centimetre per absolute degree per centimetre, is obtained by reducing the temperature gradient dT/dL to unity. The expression is then

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[18] Drude, l. c., p. 321.

$$k = \tfrac{1}{3}\,\alpha\, v\, \lambda\, N. \qquad (31)$$

It has long been known that with some exceptions the heat and electrical conductivities of pure metals, when at proper temperatures, depending upon the metal, bear a constant ratio to each other. This is the law of Wiedemann and Franz. No satisfactory explanation for the constancy has been given except that which assumes that both electricity and heat are conveyed by electrons, the one under the influence of electromotive force and the other under the influence of thermomotive force. Dividing (31) by (27) and substituting $2\,\alpha\, T$ for $m\, v^2$

$$\frac{k}{\sigma} = \frac{4}{3}\left(\frac{\alpha}{e_s}\right)^2 T. \qquad (32)$$

The following table of Jaeger and Disselhorst[19] gives the values of k/σ at 18° cent., at 100° cent., and the ratio of the latter to the former. In this table is also given the number of electrons N per cubic centimetre, calculated by Drude[20] from data concerning the optical behavior of metals, and the mean length λ of their free path.

Metal	$k/\sigma\ 10^{-8}$ (18°)	$k/\sigma\ 10^{-8}$ (100°)	$\dfrac{k/\sigma\ (100°)}{k/\sigma\ (18°)}$	$N\ 10^{-22}$	$\lambda\ 10^{6}$ cm
Aluminum....	636	844	1.32	14.	0.2
Copper.......	665	862	1.30	4.09	1.1
Silver........	686	881	1.28	6.35	0.9
Gold.........	727	925	1.27	4.36	0.9
Nickel........	699	906	1.30	9.21	0.08
Zinc.........	672	867	1.29	18.4	0.08
Cadmium.....	706	905	1.28	11.9	0.1
Lead.........	715	935	1.31	11.2	0.034
Tin..........	735	925	1.26	14.3	0.05
Platinum.....	753	1013	1.35	13.65	0.06
Palladium....	754	1017	1.35	——	
Iron.........	802	1061	1.32	14.6	0.05
Bismuth......	962	1077	1.12	10.8	0.007
Antimony....				26.	0.006

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[19] Jaeger and Disselhorst, Berliner Berichte, 38, 1899, p. 719.

[20] Drude, l. c., p. 327.

That k/σ is directly proportional to the absolute temperature is clearly indicated by the values given in the fourth column of the table. The coefficient $\frac{1}{273}$, common to gases, would give, for the temperature difference here employed, viz., 100° − 18° = 82°, the value 1.28.

The specific heats of metals are not so large as might be expected with such a large number of free electrons per unit volume.

To meet this difficulty Thomson[21] assumes that the electrons are not free for a sufficiently long interval to acquire the energy corresponding to a given temperature. They suddenly shoot out from one atom into a neighboring one. On this basis he calculates the values of k/σ and finds a difference of but about 12% from Drude's values.

Contact Electromotive Force. If two metals, having N_1 and N_2 free electrons, respectively, per cubic centimetre, be placed in contact with each other, and if $N_2 > N_1$, and the temperature be constant and uniform, then, according to the principles of the kinetic theory of gases, more electrons will pass from the latter into the former than in a reverse direction. This will give a negative charge to the former, and will thereby set up an electric field, whose lines of force will be perpendicular to the plane of separation; which will tend to reduce the velocity of the electrons entering the former and increase the velocity of those leaving it. An equilibrium will eventually result when as many electrons pass in one direction as in the other.

A contact difference of potential, of a value which can be predetermined if N_1 and N_2 be known, is established across the surface of separation. Drude[22] has derived an expression for this contact e.m.f., which at 18° cent. reduces to the form

$$E = 0.05 \log \varepsilon \frac{N_2}{N_1} \text{ volts.} \tag{33}$$

For other uniform temperatures the value of E varies directly with the temperature expressed in absolute degrees. The complete expression for E is

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[21] Report of Lecture before I. E. E., Electrical Engineering, Feb. 28, 1907, p. 381.

[22] Drude, l. c., p. 323.

$$E = \frac{4}{3} \ \frac{\alpha}{e_m} T \log_\varepsilon \frac{N_2}{N_1} 10^{-8} \text{ volts,} \tag{34}$$

where α is the thermodynamic constant, e_m the charge of an electron in electromagnetic units and T is the absolute temperature.

Seebeck Thermal Electromotive Force. If a circuit be formed of two metals connected in series, and if the difference in temperature between its two junctions be $d\,T$ absolute degrees, then the thermal electromotive force $d\,E$ set up as a result, is obtained by differentiation of (34), and equals

$$d\,E = \frac{4}{3} \ \frac{\alpha}{e_m} d\,T \log_\varepsilon \frac{N_2}{N_1} 10^{-8} \text{ volts,} \tag{35}$$

from which the value of the thermoelectric power can be obtained. This expression assumes that N_2/N_1 does not vary with T, concerning which there is as yet not sufficient experimental evidence.

From equations (34) and (35) an expression is readily obtained for the rate of absorption or development of heat when a current I (amperes) flows in the circuit. This power P, which is a measure of the Peltier effect, is expressed as follows:

$$P = E\,I = \frac{4}{3} \ \frac{\alpha}{e_m} I\,T \log_\varepsilon \frac{N_2}{N_1} 10^{-8} = I\,T \frac{d\,E}{d\,T} 10^{-8} \text{ watts.} \tag{36}$$

Drude has also obtained an expression for the Thomson effect, that is, the development or absorption of heat as the result of a current that flows through a homogeneous circuit having local temperature differences.

Electromagnetically Induced Electromotive Force. The generation of electromotive force as a result of the relative motion between a conductor and the flux of a magnetic field is a direct consequence of the ether entanglement with the electron. A force acts directly on each electron whose direction is determined by the directions of the flux and of the motion, and whose magnitude depends upon the relative velocity and the flux-density.

The Hall Effect. Consider a rectangular piece of sheet metal with a current flowing along it. If the current enter by a terminal connected to the middle point of one edge of the rectangle and leave by a terminal connected to the middle point of the opposite edge, there will be a zero potential difference between two points located respectively at the centers of the remaining opposite edges. A galvanometer connected between these last two points would give no deflection. If now a magnetic flux be passed perpendicularly through the surface of the sheet, a current will flow through the galvanometer circuit, whose magnitude will be directly proportional to the strength of the original current and to the flux-density of the magnetic field, and whose direction will be reversed if the direction of

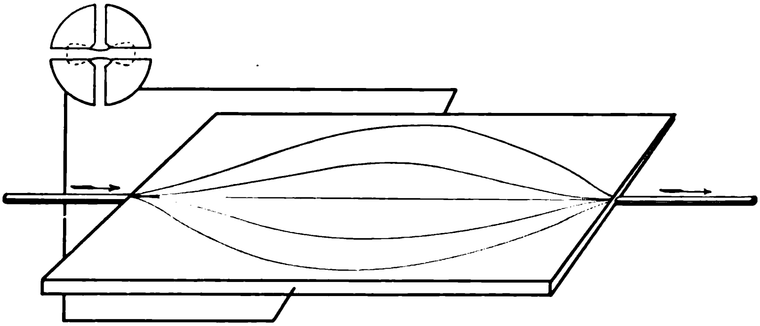
Fig. 3.—Flow lines of current.

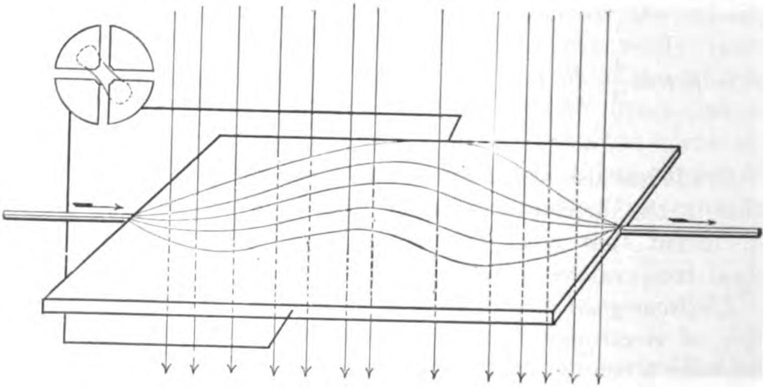
Fig. 4.—The Hall effect.

either the flux or of the original current be reversed. This phenomenon is known as the Hall effect. This effect is readily explained from the standpoint of the electron theory.

The electric current may be considered as accompanied by a procession of electrons moving in the sheet in a direction opposite to that of the current flow. Let the migration velocity of the electrons be v cm/sec, the charge of each be e_m electromagnetic units, and the magnetic flux-density be H; a transverse force F will be exerted upon each electron whose value will be $e_m v H$ dynes; and in consequence they will be forced towards one side of the sheet, and a flow of current through the galvanometer circuit will be necessary to maintain equilibrium. If no galvanometer circuit be present, a negative charge will appear at the side towards which the electrons move, and will grow until the transverse electric field which it occasions attains such an intensity E, in electromagnetic units, as to exert a force $e_m E$ dynes upon each of the electrons equal in magnitude and opposite in direction to that exerted by the magnetic field. Then

$$e_m E = e_m v H.$$

Since e_m is known and E and H can readily be obtained by experiment, it is possible to obtain the average migration velocity v of an electron from the above formula, as

$$v = \frac{E}{H} \qquad (37)$$

Boltzmann calculated v for various metals several years ago. The velocities are remarkably small for even very strong currents. Lorentz[23] gives the following values for one ampere flowing through a wire of one square millimetre cross-section: copper 0.005, nickel 0.2, and bismuth 90 cm/sec.

Some experimental results obtained in this field are not easily explained. The direction of the current in the galvanometer circuit, when an iron sheet is employed, is opposite to that which is to be expected. A thorough investigation of the Hall effect in ferromagnetic substances may shed some light upon the question of the cause of their large permeability. Thomson[24] explains the apparently inconsistent results by the assumption of a gyrostatic action of the molecule which causes the electrons to move in a different direction from that of the force exerted upon them by the magnetic field.

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[23] Lorentz, l. c., p. 588.

[24] Electrical Engineering, Feb. 28, '07.

Solid Dielectrics. Solid dielectrics probably contain some free electrons, although the number per unit volume is small compared with that in metals. To free electrons is due the conductivity of solid insulators that remains after surface leakage has been prevented. Free atomic ions are probably absent, since conduction through their mediation would result in a transport of matter with accompanying differences in the chemical and physical character of the surface layers of the dielectric when kept between conductors having a maintained difference of potential. Such transport has not been observed. If the atomic ions of a dielectric are not possessed of freedom of migration, the maintenance of a mean position of equilibrium must be due to the attractions and repulsions of unlike and like charged particles. If a distinction is to be drawn between atomic ions devoid of freedom of migration and molecular aggregates of atoms, then the latter are probably also present.

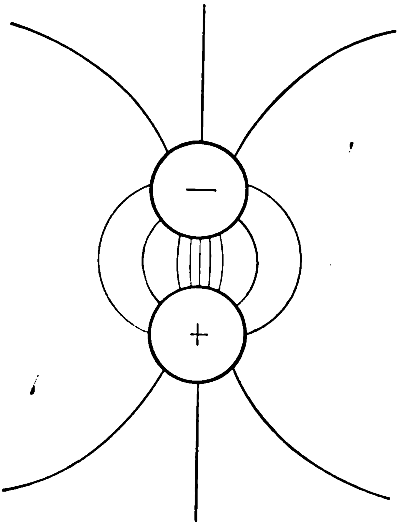

FIG. 5.—Dumb-bell Molecule.

Consider a diatomic molecule in a solid dielectric. Although nothing is known of the shape of a molecule, and although in the treatment of the kinetic theory of gases it is frequently assumed to be spherical, it seems reasonable to assume, from the standpoint of the present discussion, that it is not spherical and that it may be shaped somewhat like a dumb-bell with an atom at each end connected by a sheaf of electrostatic flux lines. Such a molecule would behave in an electric field much as would a magnetic needle of the same shape in a magnetic field. Both would orient themselves, but would not suffer translation if the fields were uniform, and the molecule would have an electric moment similar to the magnetic moment of the needle. But, while the pole distance is rigidly maintained by the steel in the needle, this is not the case with the end atoms of the dumb-bell molecule. With a sufficiently large electrostatic flux-density, the molecule would be ruptured, its oppositely charged atoms being forced away from each other by the field. The rupturing of an assemblage of such molecules in a solid dielectric would, in such a field, manifest itself as a rupture of the dielectric. The molecular-magnet theory[25] of magnetic induction in iron, can by analogy, be directly applied to solid dielectrics consisting of an aggregate of such dumb-bell molecules. The application of an electric field would orient the molecules to a greater or less extent, which would be evidenced as a residual polarization after the field was removed. Such polarization is a common occurrence. The flux due to the orientation would be superposed on the ether flux produced by the original source of the field, the dielectric thus exhibiting a larger dielectric constant than the free ether. That the dielectric constant of all solids is greater than unity is well known. Under the influence of alternating fields the configuration of orientation would be different for the same values of increasing and decreasing intensities. This would result in a dielectric hysteresis of greater or less extent accompanied by an energy loss which would be dissipated in heat. This loss in ergs per cubic centimetre per cycle G has not only been observed, but its magnitude, as dependent upon the material and maximum electric flux-density E_{max}, is expressed by a formula[26] similar to Steinmetz's law for iron, the exponent n of E_{max} lying between 1.5 and 1.95, and corresponding to 1.6 in the Steinmetz formula. If α represent a constant dependent upon the character of the dielectric

$$G = \alpha \, E^{n}{}_{max} \text{ ergs.} \tag{38}$$

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[25] Ewing, Magnetic Induction in Iron and Other Metals, p. 382.

[26] R. Threlfall, Phys. Rev., 1897, iv, p. 457; v, p. 21.

A tendency to dielectric saturation, accompanied by a reduced specific inductive capacity corresponding to the saturation and reduced permeability in iron under increase of electric flux-density, has been observed in the case of crown glass, guttapercha, megohmit, and paraffined paper.[27]

The lack of rigidity of connection between the atoms of a dumb-bell molecule permits vibration of the atoms about a mean position relative to each other. There is a natural period for such vibrations. If now an alternating electric field of this natural period be impressed upon the molecule, an inter-atomic vibration will be started at the expense of energy supplied by the field. The natural frequency is very large, of the order of those due to light disturbances. The propagation of light disturbances is always accompanied by an alternating electric field of high frequency. If now light, of such color as to have a frequency synchronous with the natural frequency of vibration of the atoms of the dumb-bell molecule, be passed through a transparent dielectric containing such molecules, its velocity therein would be reduced below that which would exist for higher or lower frequencies, and a prismatic spectrum, produced by passing white light through a prism of such dielectric, would therefore show the colors in other than their usual order, that is, the prism would cause what is termed anomalous dispersion. The natural frequency of vibration of quartz molecules is such, that radiations of wave-lengths much longer than those of red light ($\lambda = 56\,\mu$) are refracted by a quartz prism more than violet light.[28]

The argument outlined above applies equally well to molecules of greater atomicities and complexity. It is also applicable to the negatively charged electrons and positively charged remainders of atoms, if it be assumed that these can be separated under the action of an electric field. Such an assumption is made by J. J. Thomson.[29]

The Production of Light. Many efforts have been made to explain the characteristic spectra of the various chemical elements from the standpoint of the electron theory. For many reasons, such efforts can hardly be considered as successful, as clearly presented by Crew.[30] There is as yet too little knowledge concerning the relations which exist between electrons and atoms as they occur in the various forms of matter. Furthermore, hardly anything is known about the positively electrified portion of matter or about positive electricity itself. This much, however, can be considered as established; that an electron with its negative charge e_m, when accelerating a cm/sec^2, the velocity of propagation of ether disturbances being c cm/sec, radiates energy into space whose value (see equation 5) is expressed as

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[27] J. A. Fleming, Electric Wave Telegraphy, p. 137.

[28] Rubens and Aschkinass, Wied. Ann., 67, p. 459, 1899.

[29] J. J. Thomson, Phil. Mag., May, 1906.

[30] Henry Crew, Science, N. S., Vol. XXV, No. 627, p. 1-12, Jan. 4, 1907.

$$J = \frac{2}{3}\frac{e_m^2 a^2}{c} = 2.7\ 10^{-49} a^2 \text{ erg/sec} \qquad (39)$$

If by any means the sign of acceleration be changed periodically at a constant frequency having a value lying between 4 10^{14} and 8 10^{14}, then the radiant energy will consist wholly of monochromatic light radiation. Change in sign can be obtained either by reversing the direction of motion in a rectilinear path with accompanying changes in velocity (collision or impact), by merely changing the direction of the path (circle) leaving the velocity unchanged, or by both. If on the other hand the duration of the periods between reversals be variable within wide limits, then there will be non-luminous heat radiation, continuous spectrum luminous radiation, and ultraviolet radiation. In this case only a portion of the energy which is radiated is converted into light.

The acceleration which an electron may assume, varies over very wide limits. When it is considered that, within a vacuum tube of a few centimetres length, an electron can start from rest and attain a velocity of one-tenth that of light, that is 3 10^9 cm/sec, its acceleration must have been at least 2 10^{17} cm/sec. The distribution of voltage in such tubes would indicate that its acceleration near the cathode would be many times greater than this. Assuming it to be five times as great; that is, $a^2 = 10^{36}$ cm/sec^2, this electron would radiate 2.7 10^{-13} erg/sec or 2.7 10^{-20} watt.

Black-Body Radiation. According to the Stefan-Boltzmann[31] law, a black body (one which absorbs all radiations falling on it, and which neither reflects nor transmits any) at an absolute temperature of T degrees, radiates from each square centimetre of its surface an amount of energy.[32]

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[31] Stefan, Ber. d. k. Akad. d. Wiss., 79B., 2 Abth., 1879, p. 391; Boltzmann, Wied. Ann., 22, p. 291, 1884.

$$\begin{aligned} j &= 1.71\ 10^{-5}\ T^4 \text{ erg/sec} \qquad (40)\\ &= 1.71\ 10^{-12}\ T^4 \text{ watt} \end{aligned}$$

This radiation, at sufficiently high temperatures, consists of wave disturbances embodying all frequencies that are able to stimulate the optic nerves, besides a continuous series of frequencies in the infra-red and ultraviolet regions.

The portion, W, of the total radiation per cm² that is capable of stimulating the optic nerves so as to given a sensation of light is to be obtained from the equation[33]

$$W = C\left(\frac{T}{k}\right)^4 \lambda'^{-3}\ e^{-\frac{k}{\lambda' T}} \left\{\left(\frac{k}{T}\right)^3 + 3\left(\frac{k}{T}\right)^2\lambda' + 6\left(\frac{k}{T}\right)\lambda'^2 + 6\lambda'^3\right\}$$

$$- C\left(\frac{T}{k}\right)^4 \lambda''^{-3}\ e^{-\frac{k}{\lambda'' T}} \left\{\left(\frac{k}{T}\right)^3 + 3\left(\frac{k}{T}\right)^2\lambda'' + 6\left(\frac{k}{T}\right)\lambda''^2 + 6\lambda''^3\right\}$$

erg/sec (41)

where $\lambda' = 0.000039$ = wave length at violet end of spectrum in cm.

$\lambda'' = 0.000075$ = wave length at red end of spectrum in cm.
$C = 1.24\ 10^{-5}$
$k = 1.4435$
$e = 2.718$ = Naperian logarithmic base.

The visible radiation efficiency at any temperature T is therefore

$$\varepsilon = \frac{W}{j} \qquad (42)$$

Carbon filaments are generally considered to yield approximately black-body radiation.

The radiated energy is not equally distributed among the various frequencies. Planck[34] has shown that the energy radiated per cm² between wave-lengths λ and $\lambda + d\lambda$ can be represented by the equation

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[32] F. Kurlbaum, Wied. Ann., 65, 1898, p. 746; Drude, Theory of Optics, p. 515.

[33] Mendelhall and Saunders, Astrophys. Journ., 1901, p. 46.

[34] Planck, Verh. d. Deutsch. Phys. Geo., 2, 1900, p. 202; Ber. d. k. Akad. d. Wiss., Berlin, 1901, p. 544.

$$E = C\lambda^{-5} \frac{1}{e^{\frac{k}{\lambda T}} - 1} \tag{43}$$

The physiological characteristics of the normal eye are such that for different wave-lengths, different rates of energy are required to be received upon the retina in order to produce the same intensity of sensation. Therefore, while values of ε indicate the stimulative portions of radiation, they do not indicate the amounts of luminous sensation that thereby might be produced. Although the sense responsiveness of the eye for a given color varies and depends on the individual, on the portion of the retina stimulated, on visual fatigue, and on the rapidity of iris response to variations in intensity, an average sensation equivalent of W can be obtained by making use of Abney's[35] coefficients of luminosity for the normal eye. With wave-lengths as abscissae values of E are plotted as ordinates. The values of E are each multiplied by the luminosity coefficient corresponding to the wave-length and used as ordinates in plotting a new curve. If the values of λ be limited to the visible spectrum, then the area included between the first curve and the axis of abscissae, is proportional to W while the area Z between the second curve and the axis is proportional to the sensation equivalent. The luminous efficiency of the radiation is then

$$\eta = \frac{Z}{J} \tag{44}$$

As the temperature of a black body rises not only does the power radiated increase but the predominating frequency rises, that is, the wave-length λ_m at which the intensity of radiation is the greatest, decreases. At an absolute temperature[36] T

$$\lambda_m = \frac{0.2887}{T} \text{ cm.} \tag{45}$$

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[35] Abney, Color Vision, 1895.

[36] Drude, Theory of Optics, 1902, p. 523; Wien. Berl. Ber., 1893; p. 55; Wied. Ann., 49, 1893, p. 633; 52, 1894, p. 132.

The intensity of the radiation at these wave-lengths, also increase as the fifth power of the absolute temperatures.

If a black body, for example, a carbon filament, be considered as containing free electrons as well as atoms and molecules, then as its temperature is raised the mean kinetic energy of each electron will be increased. Inasmuch as the geometrical dimensions of the filament are not materially altered by the change of temperature. it is reasonable to assume that the length of free path is not increased. The increase of energy causing an increase of electron velocities will result therefore, in an increased frequency of collisions and an increased rate of change of velocities. This accounts for the direction of the shifting of λ_m with rise of temperature, and for the accompanying increase of total radiation. Many of the collisions will occur oftener than at the preponderating frequency, and others will occur less often, which accounts for the character of the distribution of radiated energy over a wide range of frequencies. The accelerations which accompany collisions of the higher frequencies are of necessity greater than in the case of lower frequencies. The radiated energy is therefore greater in the former case than in the latter, and the curve of distribution of radiated energy over different frequencies is not symmetrical but deviates from the curve of probabilities.

Selective Radiation. No material radiates in accordance with the laws of black-body radiation. One of the first conclusions of Maxwell's electromagnetic theory is that good conductors of electricity cannot be transparent. Hagen and Rubens[37] have shown how the absorbing power and the emissive power of metals can be calculated from their electrical conductivities. Their experimental results for the longer heat-waves are very satisfactory. Kirchhoff's law according to which the ratio between the emission and the absorption for all bodies has the same value, being a universal function of the absolute temperature and of the wave-length, has also been accounted for from the standpoint of the electron theory. Lorentz, using the expression for the electrical conductivity previously developed [see equation (29)] has calculated the value of this function. He then compares the amount of energy radiated from a metal within the limits of certain long wave-lengths with the experimental values obtained by Lummer and others, and finds that they are in accord.

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[37] Hagen and Rubens, Ann. der Phys., 11, p. 873, 1903.

Luminescence. At all temperatures above absolute zero all bodies radiate energy. If the nature of the body be not changed by this radiation; that is, if it continues to radiate in the same manner, as long as its temperature is maintained constant by the addition of heat, the process is termed pure temperature radiation. If, on the other hand, the body changes because of the radiation, and does not continue indefinitely to yield the same radiation although its temperature is kept constant, the process is termed luminescence. The cause of some of the radiation in the latter case does not lie in the temperature of the system but in some other source of energy. According as the extra supplied energy accompanies either chemical transformations, exposure to light, or the passage of electric currents, the processes are respectively termed chemico-, photo-, and electro-luminescence. The total radiation from a body of this class is made up of two parts—that due to its temperature and that due to the extra energy. If the intensity of radiation of a body within any region of wave-lengths is greater than that of a black-body at the same temperature, luminescence must be present. This is frequently[38] taken as a criterion for the detection of luminescence. The frequencies of luminescent radiations are more or less restricted, being often evidenced by bright-line spectral distributions. The electrons which yield these radiations are supposed to vibrate harmonically under conditions that are not yet understood. That their movements are not governed simply by chance, seems to follow from the character of the spectra. Although change in the character of the material as a consequence of its yielding luminescent radiation may not be capable of detection by chemical analysis, yet the atomic and molecular systems are nevertheless doubtless undergoing constant changes due to the loss or gain of electrons. The entrance of an electron into a system, or its ejection, must without doubt occasion complex harmonic disturbances of many or all the electrons in the system.

If luminescent radiation be confined chiefly to wave-lengths of the visible spectrum, the luminous efficiency of the body becomes high. Herein rests the economic significance of the efforts being made to advance the art of lighting by means of vacuum tube and flaming arc lamps.

A very interesting example of luminescent radiation is that which is yielded by photogenic bacteria, which are frequently found in sea-water and upon meats and fish that have been directly or indirectly infected by sea-water. They are the sources of light known as the phosphorescence of the sea. Some cases of phosphorescence in animals and in plants are explained as an infection with them. Gorham[39] has shown that the light which they give is the result of chemical transformations accompanying metabolism inside the cells of their bodies. When fed with substances such as asparagin or glycocoll they are able to grow and reproduce but not to give light. In Gorham's summary occurs the following:

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[38] Drude, Theory of Optics, p. 528.

> We therefore conclude that for light production there must be present, over and above the requirements for growth, the oxygen of the air, *sodium or magnesium*, and certain organic acids, derived from the decomposition of the carbon and nitrogen constituent of the food.
>
> The chemical energy resulting from the union of the sodium or magnesium with these organic acids, in the presence of oxygen, or from the later combustion of the products of that union, is set free in the form of light.

The brightness of these bacteria considered as sources of light is very small. Lode's[40] measurements show an intensity of emission of 0.00069 candles per square meter. This is too small to stimulate the color sense. The *bacillus lucifer* of Molisch,[41] however, is much brighter, gives a continuous spectrum in the green, blue, and violet, and is able to stimulate the color sense.

Conclusion. Although much is known concerning the size and mass of the electron, its electric and magnetic effects when in motion, and its radiation effects during acceleration, little more is known concerning its structure than that:[42]

> It is the intrinsic strain-form alone that constitutes the electron; and it is a fundamental postulate that the form can move from one portion to another of the stagnant ether somewhat after the manner that a knot can slip along a cord.

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[39] F. P. Gorham, The Photogenic Bacteria, Doctor's Thesis, Harvard Univ., May 1, 1903.

[40] Lode Zentralbl. für. Bakt., I 35, Bd., p. 524.

[41] Molisch, Leuchtende Pflanzen, 1904, p. 133.

[42] Larmor, Æther and Matter, 1900, p. 335.

EXPLANATION.

The following five articles* (pages 685–733) are " Introductions" to discussions to take place at the 24th Annual Convention of the Institute, **Niagara Falls, N. Y., June 26, 1907,** at 9:45 a.m. They are not intended to be formal or complete papers, but to serve merely as a basis or framework for discussion on the subjects with which they deal. All those connected with the Institute and desiring to take part in these discussions may do so by being present at the meeting, or if this is not possible by sending in written " Contributions."

In contributing to a discussion, whether verbally or in writing, it is requested that the matter under discussion be taken up under the several subdivisions and in the order made use of in the Introduction, and that following the treatment of these subdivisions there be introduced any other matter which the contributor may deem advisable. When the contributions are made by mail on more than one of the topics under consideration at the same meeting, it is requested that the several contributions be embodied in separate letters.

Contributions will be read at the meeting for which they are intended either in full, in abstract, or as part of a general statement giving a summary of views of those taking the same position in the matter under discussion.

It should be borne in mind that each Introduction is written in order to provoke discussion, and that there should be no hesitancy in attacking if it does not agree with the opinions of the contributor. On the other hand, if the contributor agrees with the matter of the introductions, either in whole or in part, he should state the fact.

It should also be borne in mind that the principal object of this scheme is to enable and encourage those not in a position to attend meetings to take part in a discussion. If one does not feel himself qualified to discuss certain parts of an Introduction, but is able to discuss other parts, it is to be hoped he will contribute to the latter.

Contributions to the discussion of this paper should be mailed to **Ralph D. Mershon, Chairman Transmission Committee, 60 Wall St., New York, N. Y.,** so that they will be received not later than **June 24, 1907.**

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*By Messrs. Kintner, Moody, Scholes, Rowe, and Nicholson.

A paper to be presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26, 1907.

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CHOKE-COILS VERSUS EXTRA INSULATION ON THE END-WINDINGS OF TRANSFORMERS

BY S. M. KINTNER

Surges along a transmission line are stopped and thrown back by choke-coils in a manner analogous to the reflection of water waves by a breakwater at the entrance to a harbor. The quiet of a harbor is obtained by setting up a strong wall capable of withstanding the shock of the waves that strike against it; so is the analogous quiet of a transformer obtained by placing a choke-coil in the path of a disturbance.

A choke-coil will be effective in reflecting and shielding all back of it according to its strength. The strength of a choke-coil is measured by its inductance and its insulation. If the former is small, but little reflection will take place, the surge passing through the coil and continuing beyond it. If the insulation of the coil is weak and the inductance is of sufficient value to retard the on-coming wave and throw it back on to the line, the rise of voltage will cause a discharge over the coil-face and the wave will continue past the coil. These two conditions can be likened to a breakwater consisting of piling spaced so as to have little effect in retarding an incoming wave in the first instance; and in the second instance to a breakwater of insufficient height so that the waves pass over it.

With a given choke-coil on a given line, a certain fixed amount of protection will be afforded any apparatus placed back of the coil. There is no relation between the coil and the apparatus being protected that will make the coil more or less effective in its operation of throwing back surges that come in from the line. The choke-coil will produce the same percentage of reflection regardless of what it is protecting, and consequently can be said to be affording the same protection.

Tests indicate that the same percentage of protection will be afforded by the same coil for all parts of the same transformer; that is, measurements made over 200 turns of the winding of a transformer which was being subjected to static surges from a discharging condenser: first, when the transformer was unprotected; secondly, when it was protected by a choke-coil, showed practically the same percentage of protection afforded by the choke-coil when the measurements were repeated over only 20 turns of the transformer. A long series of tests, the results of a part of which have been recently made known to the Institute by Mr. R. P. Jackson,* have convinced the writer of the truth of the above statements.

In choosing a choke-coil for a particular installation, the matter resolves itself into a consideration of: 1, the possible surge the apparatus can withstand safely; 2, the probable surge that can be transmitted over the proposed line, the line insulation indicating the maximum voltage that the surge can have during transmission; 3, the maximum allowable inductance that will not seriously affect the line regulation if an external choke-coil is used; 4, a consideration of the amount of money to be expended for choke-coils as insurance against interruption; 5, the selection of a choke-coil which will most nearly meet the above conditions, the selection being guided by the above, combined with the results of tests and curves similar to those shown in Mr. Jackson's paper.

The question of whether part of the transformer winding should be made strong enough to withstand the surges—and thus have within its own windings a choke-coil that protects the rest of the apparatus—or whether an extra coil should be used, will be discussed below.

The following is a list of the advantages and disadvantages of separate choke-coils.

Advantages:

1. On a choke-coil there is normally no voltage between turns, and consequently no tendency to hold a short-circuit in the event of a momentary surface-discharge.

2. The choke-coil permits the construction of a transformer with uniform insulation throughout. This permits the safe

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* PROCEEDINGS A. I. E. E. December, 1906, p. 843.

working of such a transformer with several methods of connection to the line.

3. The choke-coil allows the safe use of a cheaper transformer.

4. The choke-coil can be insulated much more strongly than a transformer.

Disadvantages:

5. Increase in the number of pieces of apparatus.

6. Increase in complication of station wiring when external choke-coils are used.

1. One of the greatest advantages of choke-coils over extra insulation on the transformer windings lies in the fact that the choke-coil does not normally have a voltage between turns. In the event of a choke-coil insulation failing between turns, nothing in the nature of a short-circuit results, as there is no voltage-difference to maintain an arc. On the other hand, a failure between turns in the insulation of a transformer is vital, and it is almost certain to result in a transformer burn-out. A part of the choke-coil will be cut out and will be inoperative, and consequently the coil less effective as a whole is the worst that can result from such a failure in the coil insulation.

2. The second point of superiority of the choke-coil—allowing the use of a transformer which is uniformly insulated—is of great advantage to the builder, as well as to the operator.

In the majority of specifications for power transmission transformers, it is required that the transformer be capable of operating at one-half voltage at full rated capacity. In general, it is expected also that occasion may arise when the transformer may be operated either in star or delta connection.

It is evident that to meet all the above conditions with certain parts of the transformer specially insulated, involves some very complicated insulation arrangements, and requires extra insulation on a large part of the whole transformer.

3. In consideration of the third point, that of cost of transformer, it should be remembered that the better grade of power transmission transformers of 1000 kw. and upward are wound with copper ribbon, one turn per layer. These coils are insulated uniformly throughout, so as to stand momentary voltages of from 5000 to 9000, between turns. In order to get this result, only about 8 to 10% of the available winding space can be used for copper, the rest being given up to solid insulation and oil-ventilating ducts. An increase in insulation over the above is not desirable with the insulating materials in use at this time;

for two reasons: first, the coils cannot be made strong enough mechanically to stay in place under the shocks to which they are subjected; secondly, the extra insulation retains the heat from the copper, and thus either burns out or necessitates a much lower rating of the transformer.

It is very difficult for workmen to handle large coils with extra heavy insulation without injury to the insulation.

It is therefore evident that a cheaper transformer can be employed when a protecting choke-coil is used.

4. The fourth advantage of the choke-coil is that much better insulation can be obtained in it than in a transformer. This is due to the fact that more material can be used between turns, and it can be disposed to better advantage by allowing more extension beyond the copper than could be employed economically in a transformer coil; also the shape of the coil is much simpler than that of the average transformer coil and thus more readily lends itself to better insulation.

5–6. The disadvantages of the choke-coil over the extra insulation are two in number; first, an increase in the number of pieces of apparatus; secondly, an increased complication in the station wiring when an external choke-coil is used. Both of these disadvantages are very materially reduced when it is permissible to mount the choke-coils inside of the transformer tank. It is thus possible to make the choke-coil a part of the transformer terminal, the coil being connected on the inner end of the terminal.

For some installations it is possible to use choke-coils mounted out in the air and thus made a part of the station wiring, but in general the oil-insulated coil is to be preferred. Past practice has been to have each oil-insulated choke-coil mounted in its own tank, but there seems to be no good reason why they cannot be placed inside the transformer tank and thus save considerable floor space as well as outside wiring.

After a thorough consideration of what is involved in the above points, it is the writer's opinion that for a given expenditure to provide protection against surges, more can be obtained by the use of choke-coils than by extra insulation on the transformer.

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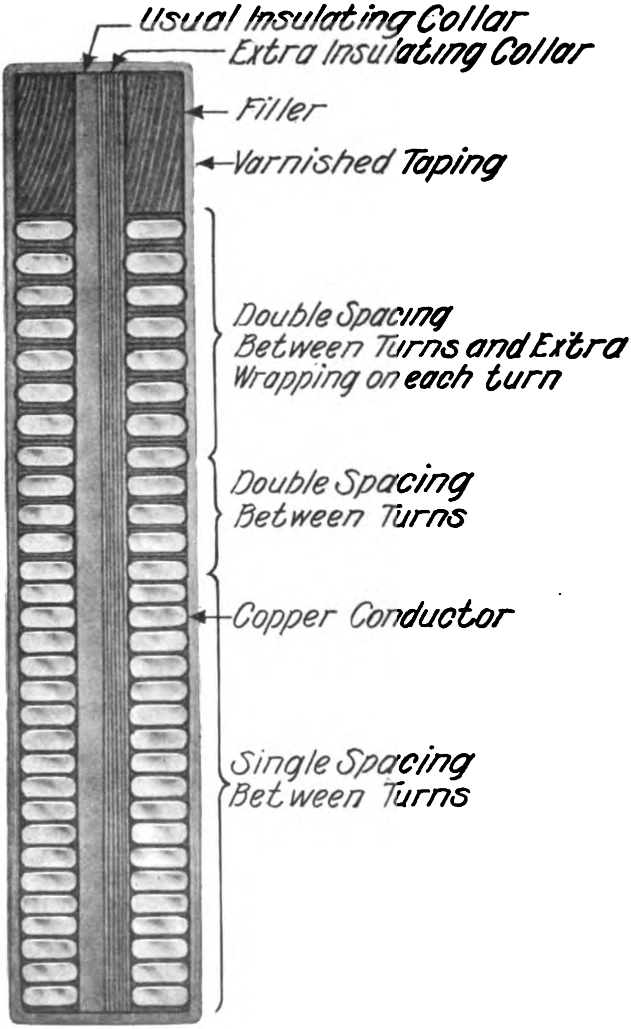
PROTECTION OF THE INTERNAL INSULATION OF A STATIC TRANSFORMER AGAINST HIGH-FREQUENCY STRAINS

BY WALTER S. MOODY

Most forms of lightning-arresters, especially of the multigap type, protect transformers against high-frequency even better than against low-frequency strains so far as these strains exist between either the high- or the low-potential windings, or between either of these windings and any other part of the transformer; because the high frequency causes a greater condenser charging current to flow across the gaps at the line end of the arresters, thereby reducing the resistance of these gaps. They do not, however, always prevent strains far in excess of normal being thrown upon the adjacent turns and layers of the windings; because, although the high frequency strain may be less than the working voltage, the frequency, and consequently the wave-length may be, and generally is, such as to concentrate this strain on a relatively small portion of the turns at the end of the windings connected to the line.

There is a wide range in the frequency of the oscillations that may be set up in a given circuit under varying conditions due to atmospheric disturbances, partial grounds, switching, etc., this range easily extending from normal to several hundred thousand cycles. In the effort to impede all or a greater part of the high-frequency disturbances that try to penetrate the transformer windings, it has been quite common practice to place reactance-coils between the lightning-arresters and the transformers. While such coils are undoubtedly advisable and are quite effective, their use is attended with some objections.

A wide range is found in the size of such coils employed by different authorities, varying from, say, 10 ft. of conductor wound in a small diameter open spiral, to several hundred feet wound in forms more difficult to insulate. Evidence of more or less effectiveness of any of the different forms is usually forth-


Usual Insulating Collar
Extra Insulating Collar
Filler
Varnished Taping
Double Spacing Between Turns and Extra Wrapping on each turn
Double Spacing Between Turns
Copper Conductor
Single Spacing Between Turns

Cross Section of Transformer Coil Showing Reinforced Insulation

FIG. 1

coming, inasmuch as sooner or later there are sure to be conditions that will generate very high voltages and frequencies.

If, however, the reactance is such as to be effective against moderately high-frequency oscillations, it must, since it is connected between lightning-arrester and transformer, offer a very high impedance to the high frequency of the oscillatory currents which will usually be set up within the transformer itself, when a bound charge within it, is released by a stroke of lightning relieving some overhanging cloud. Under such conditions it is almost as bad to hold back the charge in the transformer as to keep a wave from entering under other conditions.

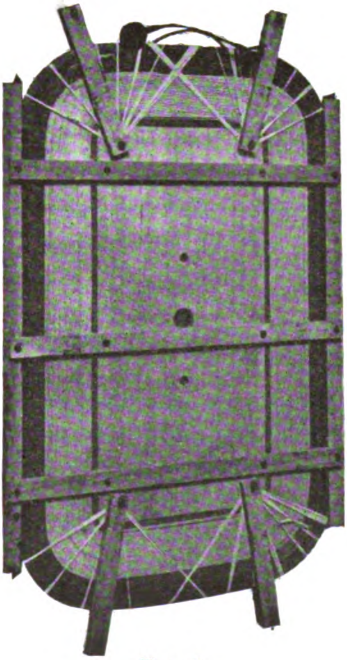


Fig. 2.

It is not my intention to add anything to what has been so ably said by Mr. Percy Thomas, Doctor Steinmetz, and others regarding the theoretical considerations involved in this problem. I simply wish to explain how a theory that very little preventive reactance is necessary to protect the winding of a transformer whose outer turns are heavily insulated has been carried out and tested on a large scale during the last four years.

The idea was naturally first put into practice in connection with large high-voltage transformers, but it has been gradually extended (although not so thoroughly) to smaller units operating on pressures as low as 10,000 volts. Thin coils, wound with one turn per layer of flat conductor, such as are commonly used in all the better sort of large transformers, are best adapted to such reenforcement of the insulation between turns.

It is practicable to reenforce a considerable portion of the turns of a large transformer coil so that it will withstand from 2,000 to 20,000 volts per turn, without greatly decreasing the space-factor of the winding or causing any considerable increase in cost. It is not practical to use as heavy insulation as this in smaller units, but as the size decreases, the length of a turn also decreases, so that the difference of potential between two turns due to a given high-frequency wave is correspondingly less. One should aim, therefore, to have, not a given insulation strength per turn in this reenforced portion of a winding, but a given strength per foot. In like manner it is desirable to reenforce, not the same percentage of the total length of conductor in all cases, but more nearly the same total length, since a given wave will penetrate about the same linear distance into a transformer winding whatever the total length of conductor may be.

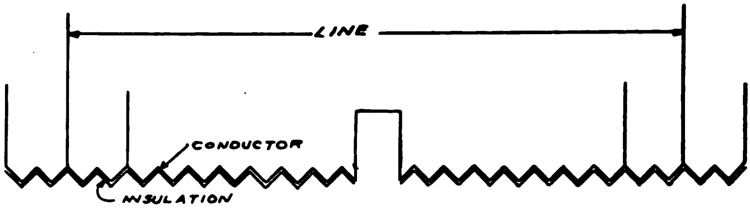


DIAGRAM OF TRANSFORMER WINDING SHOWING TAPS FOR DIFFERENT VOLTAGES BROUGHT OUT NEAR THE ENDS OF THE WINDING

FIG. 3

In large transformers wound for 75,000 volts or less, it is practicable to resist a high-frequency wave whose magnitude is equal to the working voltage in some hundred feet or less of conductor. This means that a wave-length of 200 ft. or more, corresponding to a frequency of, say, 5,000,000 cycles, could be taken care of by such a transformer. If, in addition to this reenforcement, the transformer has external reactance of some 50 ft. in length, a very considerable reduction of potential between the first few turns will result.

Figs. 1 and 2 show a coil of a 2000-kw. 60,000-volt transformer in cross-section and side view respectively, which have such tapered reenforcements of the insulation between the outer turns. The cross-section clearly shows the three different thicknesses of spacing insulation between turns, and the side view of the coil on the form on which it was wound shows the extra insulating on the very first turns where the voltage is likely to be more than could be economically insulated against by spacing insulation only.

The evident desirability of limiting the reenforced insulation to as short a length of the end portions of the winding as will accomplish the desired results, indicates the need of a different location of tap connection than usual. Few transformers for transmission work are made without taps to admit of operation with different ratios of transformation. Frequently, such taps cover a range anywhere from 10 to 30% of the winding, and if they are located so as to cut out the end portion of the turns, one must reenforce the insulation well within the inside tap or perhaps some 40% of the total winding.

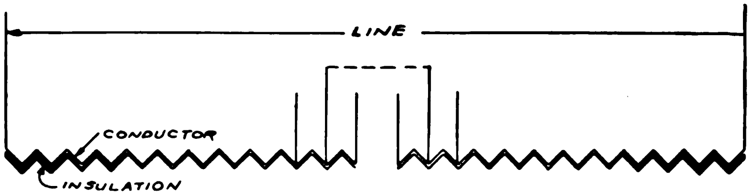


DIAGRAM OF TRANSFORMER WINDING SHOWING TAPS FOR DIFFERENT VOLTAGES BROUGHT OUT NEAR THE CENTRE OF WINDING AND REINFORCED INSULATION AT ENDS

FIG. 4

It has been our practice for some years, therefore, so to locate tap connections that they will cut out centrally located turns instead of end-turns, thereby not only placing them in an essentially safer position, but also avoiding the necessity of any more reenforcement than is required when all the winding is in service.

Some 750,000-kw. capacity of transformers embodying these ideas ranging in size from 300 to 7500 kw. and wound for 5000 to 80,000 volts have been built in both air-blast and oil-immersed types. Most of these have been installed with a small protective reactance, but many without such protection; and not one of these transformers has yet failed from any weakness of the internal insulation, although a considerable proportion of the transformers has been installed for three years.

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TRANSMISSION LINE TOWERS AND ECONOMICAL SPANS.

BY D. R. SCHOLES.

For any given transmission line there is a certain length of span which is most economical. A determination of what the economical span is, in any case, can only be made by obtaining data showing the variation of each item of cost which changes with the length of span. In a steel-tower line the cost of the tower is probably the most important among those items which vary with the length of span. As the span is made longer, the towers must be made higher and stronger. The purpose of this paper is to describe a method by which the relation between the height, strength, and cost of a tower of given form may be expressed. The application of this method to the problem of fixing the economical span will also be shown.

A transmission tower has, in general, three duties to perform:

1. It must have strength to resist wind pressure on its various members.

2. It must have strength to withstand certain external loads due to cables, guys, etc.

3. It must have strength to sustain its own weight.

The weight of a given transmission tower may therefore be considered to be made up of three components, each component corresponding to one of these sources of stress. The following equation may then be written for the weight of the structure shown in diagram in Fig. 1,

$$W = W_W + W_L + W_S \qquad (1)$$

in which W = total weight.
W_W = weight necessary to provide strength against wind pressure.
W_L = weight necessary to provide strength against external loads.
W_S = weight necessary to enable the structure to sustain its own weight.

Assume that the structure shown in Fig. 1 has been designed for a certain wind pressure, and for certain external loads of given amount and manner of application. Each member in the structure may be considered to involve three components of thickness, each component corresponding to one of the three general sources of stress. In determining the value of W_W, the stress in each member resulting from wind pressure alone would first be computed; with this as a basis, the component of thickness of each member necessary to sustain the stress due to wind pressure alone would then be calculated. Having determined the component of thickness of each member corresponding to the stated wind pressure, the value of W_W would follow directly. A similar method would be used in finding W_{SL} and W_S.

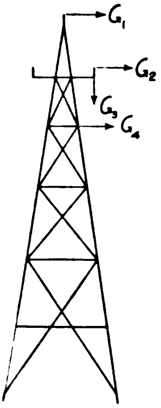

FIG I

This method will, perhaps, be made more clear by referring to Fig. II, which shows in cross-section one of the members of the tower of Fig. I.

In the figure,

t = total thickness.

t_W = thickness corresponding to wind pressure.

t_L = thickness corresponding to external loads.

t_S = thickness corresponding to weight of structure.

t_{SW} = thickness corresponding to component W_W of the weight of the structure.

t_{SL} = thickness corresponding to component W_L of weight of structure.

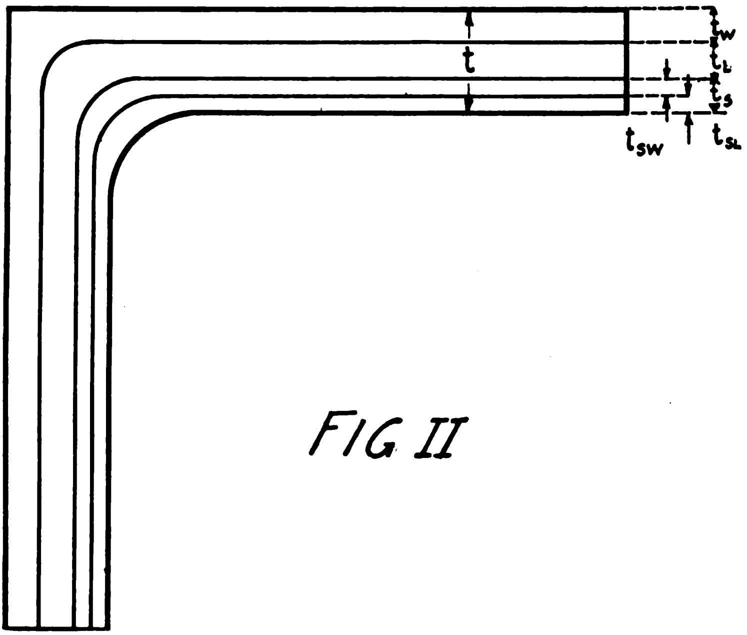

FIG II

It is seen that $t = t_W + t_L + t_S$ (2)

and, $t = t_W + t_L + t_{SW} + t_{SL}$ (3)

since $t_S = t_{SW} + t_{SL}$.

The thickness of any other member of the tower may be considered to be divided up into parts in the same manner. Since t_S is divided into the parts t_{SW} and t_{SL}, a corresponding division may be made in the term W_S of equation (1) which gives

$$W = W_W + W_L + W_{SW} + W_{SL} \quad (4)$$

where W_{SW} = weight necessary to provide strength to sustain

W_W and W_{SW}, and W_{SL} = weight necessary to provide strength to sustain W_L and W_{SL}.

The structure shown in diagram in Fig. I involves members of three general kinds; namely, beams, struts, and tension-members.

The bending moment produced in a given beam by a given load W may be expressed by the equation,

$M = CWl$, where (5)
M = maximum bending moment
l = distance between supports
C = constant, dependent on the manner in which the load is distributed. The relation between the bending moment and the stress in the most remote fiber of the beam is given by the equation,

$$M = \frac{PFk^2}{e}\text{, where} \tag{6}$$

M = bending moment
P = stress per unit area in most remote fiber of beam
F = cross-sectional area of beam
k = radius of gyration of beam section
e = distance of most remote fiber from neutral axis.

Combining these two expressions, the equation

$$W = \frac{P'Fk^2}{Cle} \tag{7}$$

is obtained, which gives the load which the beam will carry, P' being the ultimate strength of the material in the beam.

Now if k is the radius of gyration of a given figure, the radius of gyration of a second figure similar to the first but of different size is equal to nk, n being the ratio between corresponding linear dimensions of the two figures.

If, therefore, a second beam be considered, exactly similar to the first, but of different size and length, n being the ratio between corresponding linear dimensions of the two beams, the load which this second beam will carry is

$$W_2 = \frac{Pn^2Fn^2k^2}{Cnlne} = n^2\frac{PFk}{Cle}\text{, and } \frac{W_2}{W} = n^2 \tag{8}$$

Expressed in words, this relation may be stated as follows: The load which a beam of given form will carry varies as the square of its linear dimensions.

The strength of a strut against compressive stress is given by Rankine's formula:

$$W = \frac{P' F}{1 + C\frac{l^2}{k^2}}, \text{ where} \tag{9}$$

W = ultimate strength of strut
P^1 = ultimate compressive strength of material
F = cross-sectional area
l = length
k = radius of gyration
C = constant, depending on kind of material.

And the strength of another strut, exactly similar to the first but of different size and length, n being the ratio between corresponding linear dimensions of the two struts, is

$$W_2 = \frac{P'n^2F}{1 + C\frac{n^2\,l^2}{n^2\,k^2}} = n^2\,\frac{P'F}{1 + C\frac{l^2}{k^2}}, \text{ also } \frac{W_2}{W} = n^2 \tag{10}$$

Expressed in words, this relation may be stated as follows: The load which a strut of given form will carry, varies as the square of its linear dimensions.

The strength of a tension member is directly proportional to its cross-sectional area; that is, it varies as the square of its linear dimensions.

An investigation of the action of a member subjected to torsional loads, similar to those just made for beams, struts, and tension-members, would show a like relation; that is, the load which a member of given form subjected to torsion will carry, varies as the square of its linear dimensions. This investigation is not undertaken here, however, because members of this character are little used in transmission towers.

Returning to the structure shown roughly by Fig. I. It is usually assumed that the actual pressure on any part of such a structure, produced by a wind of given velocity, is directly proportional to the exposed area of that part. Now the exposed area of any part is, in general, dependent on its length and breadth, but not upon its thickness. It therefore follows that if the structure shown in Fig. III is geometrically similar to that of Fig. I, in every respect except the thickness of its parts, and is of different size, the ratio between corresponding linear dimensions being n, the load produced on any part of the second structure by a wind of given velocity is equal to n^2 times the load produced on the corresponding part of the first structure by the same wind. It also follows that the stress in any member of the second structure under these conditions, due to wind pressure, is equal to n^2 times that in the corresponding member of the first structure.

For the structure of Fig. III,

$$W' = W'_{W} + W'_{L} + W'_{SW} + W'_{SL} \qquad (11)$$

and

$$t' = t'_{W} + t'_{L} + t'_{SW} + t'_{SL} \qquad (12)$$

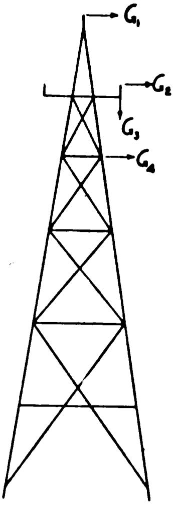

FIG III

From the foregoing discussion of the relation between the size and strength of beams, struts, etc., of given form, it is evident that

$$t'_{W} = n\, t_{W} \qquad (13)$$

and

$$W'_{W} = n^3 W_{W} \qquad (14)$$

both structures being calculated for the same wind pressure.

Again referring to the equation for beams,

$$W = \frac{P'Fk^2}{Cle}, \text{ or } F = \frac{WCle}{P'k^2} \qquad (15)$$

It is evident that if k and e can be kept constant, the sectional area which a given beam must have to sustain a load distributed in a given manner varies directly as the load and directly as the length of the beam. The sections commonly employed as beams are angles, channels, and I-sections. By reference to any handbook of such sections it will be seen that for any of these sections of a given nominal size the area of the beam may vary considerably without producing more than a negligible change in the value of k or e.

Hence, if after the nominal size of a beam has been determined, it is desired to vary either the load or the length of the beam, the sectional area should be made to vary directly as the load and directly as the length of the beam.

From the formula for columns,

$$W = \frac{P'F}{1 + C\frac{l^2}{k^2}},\ F = \frac{W\left(1 + C\frac{l^2}{k^2}\right)}{P'} \qquad (16)$$

it is seen that, if the ratio l/k is kept constant, the strength of the column is directly proportional to its cross-sectional area.

From the nature of a tension-member, its strength is proportional to its sectional area.

Again refer to Fig. I. It is assumed that this structure is subjected to the loads G_1, G_2, G_3, etc., these loads being placed upon it through cables, guys, or the like. The application of each of these loads will, in general, produce certain stresses in each of the members of the structure. The stress in a given member produced by a given load will be directly proportional to the load, and the magnitude of the stress will depend on the particular position which the member occupies. If a certain system of loads, as G_1, G_2, G_3, and G_4, is applied to the structure, the resultant stress in any given part may be considered to be made up of the components $A\,G_1$, $B\,G_2$, $C\,G_3$, and $D\,G_4$—A, B, C, and D being constants. Also, if each of the loads is multiplied by a factor r, the resultant stress in any member will also be multiplied by that factor.

Moreover, if a system of loads as G_1, G_2, G_3, etc., be similarly applied to another structure geometrically similar to that of Fig. I, but of different size, the stress produced in a given member of the second structure by these loads will be equal to that produced by them in the corresponding member of the first structure. In other words, the stress in any member is dependent only upon the geometrical form of the structure and the amount and manner of application of the loads producing it, and is not affected by the actual size of the structure.

Let the structure indicated in Fig. IV be geometrically similar to that of Fig. I in all respects except the thickness of its members. Let the system of loads, $r\,G_1$, $r\,G_2$, $r\,G_3$, and $r\,G_4$, applied to this structure be similar to that applied to the structure of Fig. I, but of different magnitude, the ratio between corresponding loads being r. Also let the structure of Fig. IV. be designed for a different wind pressure from that of Fig. I, the ratio between the wind pressures per unit area in the two cases being p.

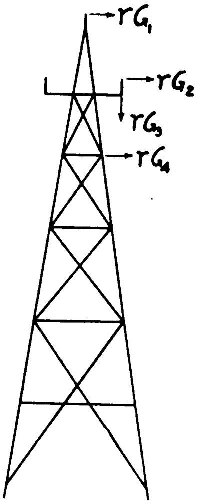

FIG IV

For the structure of Fig. IV,

$$W'' = W''_{W} + W''_{L} + W''_{SW} + W''_{SL} \tag{17}$$

$$t'' = t''_{W} + t''_{L} + t''_{SW} + t''_{SL} \tag{18}$$

In view of the relations pointed out between the length, sectional area, and strength of the various kinds of members involved in the structures, it follows that

$$W''_{W} = n^3\,p\,W_{W} \tag{19}$$

$$W''_{L} = n\,r\,W_{L} \tag{20}$$

$$W''_{SW} = n^4\, p\, W_{SW} + \ldots . \qquad (21)$$

$$W''_{SL} = n^2\, r\, W_{SL} + \ldots . \qquad (22)$$

To make equations (21) and (22) strictly accurate, terms must be added to represent the weight added to provide for the strength necessary to take care of each individual increment of weight. This will involve a convergent infinite series in each case. All terms of these series, except the first, are, however, relatively unimportant and will therefore be neglected.

Substituting in equation (17)

$$W'' = n^3\, p\, W_W + n\, r\, W_L + n^4\, p\, W_{SW} + n^2\, r\, W_{SL} \qquad (23)$$

This is a general equation, and, given the values of W_W, W_L, W_{SW} and W_{SL} for the structure of Fig. I, it makes it possible to calculate the weight of the structure of Fig. IV. without going through the routine of calculating the stresses in each member and the sizes and weights of the parts necessary to carry these stresses.

The application of this formula to the problem of fixing the economical span for a given transmission line is obvious. A tower for a given length of span would be designed to furnish the strengths necessary for that span. The design would be made in accordance with the manufacturing facilities available for producing the structures. The stresses in each member would be carefully calculated and the values of W_W, W_L, W_{SW} and W_{SL} found for the structure. Having found these values, the weight of any similar structure for any length of span could be determined by substitution in equation (23).

It is to be observed that this method of treating the case assumes that both wind loads and external loads are to be applied to the structure simultaneously. This is usually the case. In other cases, however, the method to be pursued would be similar, but modified to suit the peculiarities of the case.

It is also to be borne in mind that formula (23) contemplates that variations in the cross-section of any member will be made in such manner that the radius of gyration of the section will be kept proportional to n in every case, and also that no appreciable variation from geometric similarity will occur. These assumptions do not involve any appreciable inaccuracy within the range of ordinary practice.

Before the problem of providing steel towers for supporting the cables of a given transmission line can be considered, the general features of the line, its voltage, size of conductor, etc. must be fixed. To show the application of the formula just developed, the following set of general assumptions has been selected as a working basis, and it is believed that they are in accord with average high-grade practice.

General Assumptions.

System: three-phase alternating current.

Conductor: 400,000 cir. mils. stranded copper. Cross-sectional area 0.3145 sq. in. Outside diameter 0.73 in. Weight per foot 1.22 lb.

Spacing: 7 ft. delta, for 500-ft. span.

Minimum clearance: 30 ft. between ground and lowest conductor at center of span.

Temperature range: 40° fahr. to 110° fahr.

Sleet: 0.5 in. all around cables. Diameter of conductor with sleet 1.73 in. Weight per foot with sleet 1.98 lb.

Wind pressure: 30 lb. per square foot normal to plane surfaces.

Test factor of safety: 2.

It is further assumed that at occasional intervals along the line, the structures will be stayed by guy-cables in the direction of the line, and that the cost of such staying will not vary with the length of span. To provide in all structures a certain amount of strength against loads on the insulators, in the direction of the line, it is assumed that in the tower for the 500-ft. span, an unbalanced test load of 2000 lb. will be applied to the top of each insulator pin in a horizontal direction parallel to the line.

In explanation of the term " test factor of safety," it may be said that it has become usual for purchasers, in issuing specifications for towers, to require that the structures must show, under actual test, their ability to withstand the loads due to the assumed wind pressures, weights, etc., with a certain factor of safety. In calculating the load to be applied to the top of an insulator pin, for instance, to test it for strength against wind pressure on cables, the effective area of the cable with sleet would be multiplied by the stated wind pressure and by the factor 2. The load thus obtained would then be actually applied to the structure, and its acceptance would depend upon its ability to withstand such tests. In order that the structure may have a certain margin of strength over and above that actually required to withstand tests based on a test factor of safety of 2, the sizes of the members will be calculated with reference to a factor of safety of 2.5 based on ultimate strength.

In determining the sag corresponding to each length of span, reference has been had to the curves given in Fig. 9, calculated by Mr. Ralph D. Mershon, and here reproduced through his courtesy. These curves indicate in each case the sag for maximum temperature, this sag being so determined that, when under minimum temperature and maximum wind and sleet loads, the conductor will not be stressed beyond its elastic limit.

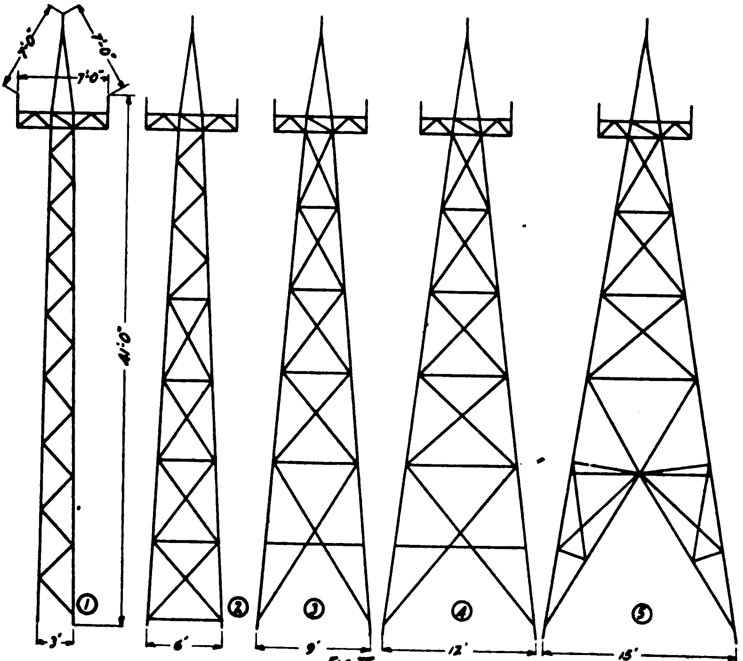

FIG. V

With the foregoing set of conditions at hand, computations have been made of the cost of each of a series of structures for a 500-ft. span, these structures being of varying width of base but uniform in height. The purpose of these computations is to show the relation between the width of base and cost for such structures, and to obtain an indication as to what ratio between height and width of base is most economical. This series of structures is shown in diagram in Fig. V. A curve is given in Fig. VI showing the relation between the width of base and the cost per structure. The cost of each structure has been figured on a basis of $4.50 per 100 lb. delivered in the field. The construction involves standard angle and flat steel sections, standard butt-weld pipe, and some simple forgings. It has been assumed that all parts would be properly galvanized, so no limitation has been made as to the minimum thickness of material, it being simply required that the members be of sufficient strength to meet the conditions laid down. The construction admits of shipment knocked down and bundled, and it is believed that the figure $4.50 per 100 lb. for structures of this class delivered in the field, is quite safe.

It will be seen, by reference to the curve in Fig. VI, that the cost of the structure alone is least when the ratio of width of base to height is about 1 to 4. This conclusion has reference, of course, only to the span of 500 ft. and to the conditions and type of construction adopted.

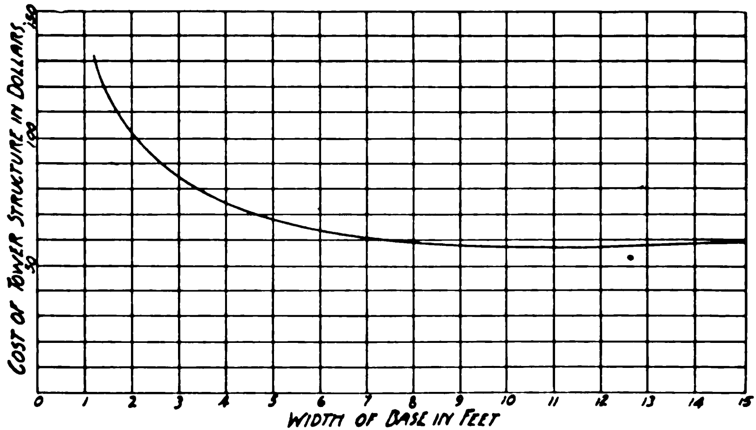

FIG VI

The width of base of the structure has an important bearing on the cost of the line, aside from its effect on the cost of the tower structure itself, since it affects the cost of foundations, the cost of right of way, and the cost of assembling and raising the structure in the field. Now it is a difficult and uncertain matter to estimate the variation of cost of these items for a general case. Hence a determination of the economical width of base for certain assumed conditions would be of but little interest in the present connection.

APPLICATION OF THE FORMULA.

The structure having a width of base equal to one-fourth its height has been selected as a basis for calculations of the weights of towers for longer spans. An investigation of this structure

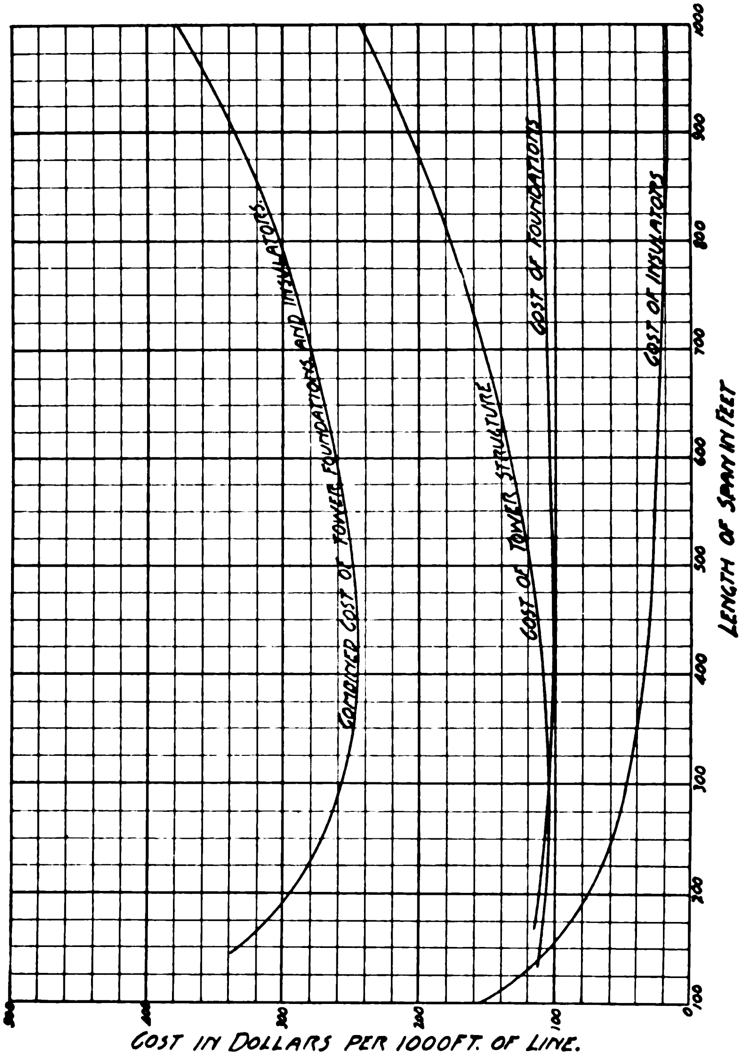

FIG. 7.

has been made to determine the values of W_W, W_L, W_{SW}, and W_{SL}, and the following values arrived at:

$$W_W = 383 \qquad W_{SW} = 34$$
$$W_L = 813 \qquad W_{SL} = 60$$

The table given below gives the results obtained by means of the formula for a series of towers similar to No. 4 in Fig. V, but for spans up to 1000 ft. Since all towers in the series are to be for the same wind pressure, p is equal to unity in each case. Also, r is proportional to the length of span, since the external loads are due to wind pressure on the cables and the weight of the cables.

These results are shown graphically in Fig. 7 by the curve which gives the relation between the length of span and the cost of towers per thousand feet of line. By properly representing to this same scale the cost of insulators, foundations, right of way, etc. per thousand feet of line, corresponding to the various lengths of span, and adding the corresponding ordinates of all these curves, a resultant curve will be obtained. This resultant curve will show the relation between the length of span and cost of those items which vary with the length of span, and it will therefore indicate the economical span for the assumed conditions.

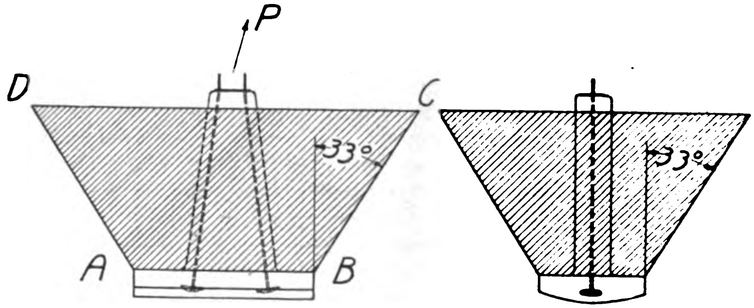

FIG VIII

A curve showing the cost of insulators per 1000 ft. of line is given in Fig. 7, the insulators having been figured at $5.00 each, erected in the tower and with the conductor secured to them.

The curve in Fig. 7, showing the cost of foundations per 1000 ft. of line has reference to the type of foundation shown in Fig. VIII, and to the following method of calculation.

It is a usual assumption that the strength of a foundation against a force tending to pull it out of the ground is directly proportional to the weight of the foundation plus the weight of earth contained in the figure *A B C D*.

If the foundation in Fig. VIII has strength to resist a resultant force P, a second foundation, exactly similar to it but of

TABLE 1.

Span	Sag	Height	n	n^2	n^3	n^4	p	r	$n^3 p w_W$	$n r w_L$	$n^4 p w_{SW}$	$n^2 r w_{SL}$	w''
200	2.0	32.0	0.780	0.608	0.475	0.370	1	0.4	182	254	13	15	464
300	4.5	34.5	0.832	0.692	0.576	0.479	1	0.6	221	406	16	25	668
400	7.5	37.5	0.915	0.837	0.766	0.701	1	0.8	294	596	24	40	954
500	11.0	41.0	1.00	1.00	1.00	1.00	1	1.0	383	813	34	60	1290
600	15.5	45.5	1.11	1.23	1.37	1.51	1	1.2	523	1082	52	89	1746
700	20.5	50.5	1.23	1.51	1.86	2.28	1	1.4	703	1405	78	128	2314
800	26.0	56.0	1.366	1.86	2.55	3.46	1	1.6	978	1778	118	179	3053
900	33.0	63.0	1.537	2.36	3.62	5.57	1	1.8	1386	2250	190	255	4081
1000	40.5	70.5	1.72	2.96	5.09	8.76	1	2.0	1950	2800	298	356	5404

different size, would have strength to resist the force $n^3 p$ n being the ratio between corresponding linear dimensions of the two foundations. Now it seems fair to assume that the cost of such a foundation would vary directly as its volume. The cost of the foundation would therefore vary directly as the resultant force which it is capable of resisting.

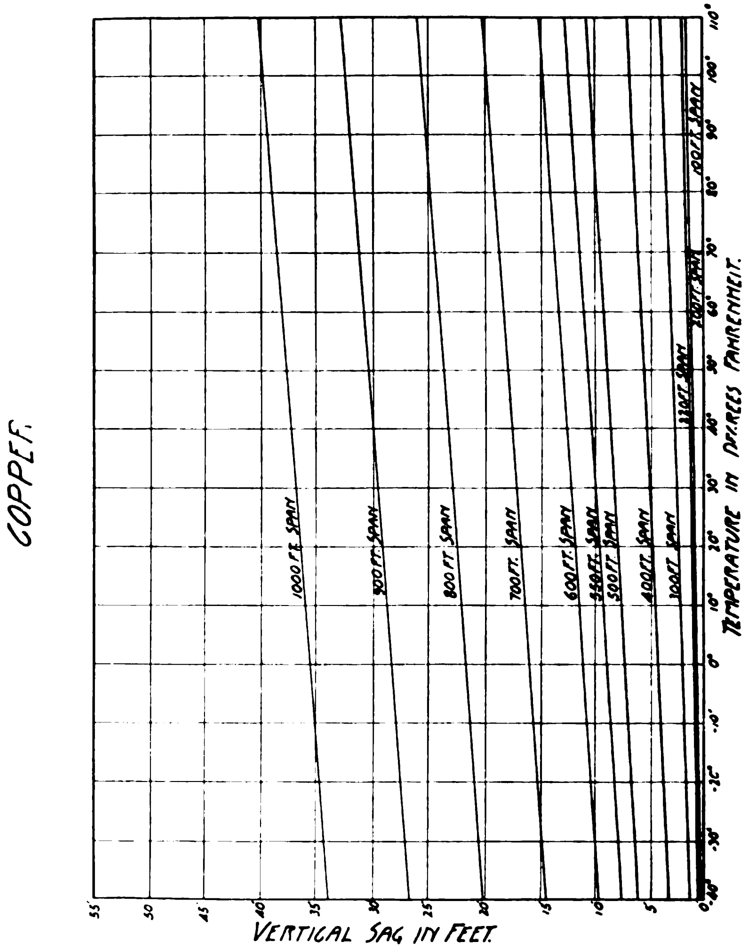

FIG. 9.

Referring to some experiments made at Chicago on a foundation similar to that of Fig. VIII, and to the records showing the actual cost of the foundation in the field, ready to receive the structure, the following basis for calculation was obtained:

Resultant force sustained by foundation.....	24,000 lb.
Cost of foundation........................	$15.25

By calculating the resultant force which would come upon the foundation from each of the structures given in Table I, and making the cost of foundation for each structure proportional to that force, on the basis of the data above given, the curve showing the foundation cost per 1000 ft. of line given in Fig. 7 was obtained. It is to be observed that this curve is quite flat, indicating that the foundation cost does not vary to any great extent as the length of the span is varied.

The curve of combined cost of towers, foundations, and insulators was obtained by adding the respective ordinates of the curves giving the separate costs of these items. This curve indicates that, for the assumed conditions, a span of about 425 ft. would be most economical.

It is to be observed that in the foregoing solution the determining factors are the tower cost and the insulator cost. As the price per insulator is increased, the economical length of span would be increased, and vice versa; in other words, the higher the voltage the longer the span should be.

For a low-voltage line the economical span would be somewhere between 300 and 400 ft., as far as the methods of calculation here employed can determine. Each structure in this case would, however, be a very light affair. It is probable that in the average case a somewhat longer span would be decided upon in order to give each structure greater individual strength and thus make it safer against damage due to external causes.

In case it is desirable to impose limitations of this sort, the formula must be modified accordingly, by subdividing the component of weight into parts; as for instance, by letting

$$W_L = W_{G1} + W_{\ \ 2} + W_{G3} + W_{G4}$$

where W_{G1}, W_{G2}, W_{G3} and W_{G4} are components of weight corresponding to the loads G_1, G_2, G_3 and G_4 respectively.

These loads may then be made to vary at different rates, or some may be kept constant and the others varied in such manner as may be desired. Suppose, for example, it is assumed that each structure should have strength to resist the loads due to the breakage of any two conductors. These loads would be the same regardless of the length of span, whereas the loads due to wind pressure on the cables would vary according to the length of span.

These assumptions will, in general, tend to make the economical span longer.

A paper to be presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 28, 1907.

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LIGHTNING-RODS AND GROUNDED CABLES AS A MEANS OF PROTECTING TRANSMISSION LINES AGAINST LIGHTNING

BY NORMAN ROWE

The following is practically a summary of lightning trouble during the years 1904, 1905, and 1906, on a steel-tower, long-span transmission line in the states of Michoacán and Guanajuato, Mexico.

The main transmission line, built in 1903, was the first one constructed on steel towers. These towers were of standard type, the height being 40 ft. from the top of the cross-arm to the ground. Three wires were placed upon the towers in the form of an equilateral triangle, the upper wire being supported upon a 3-in., extra heavy pipe, which formed the continuation of the tower; the other two being placed at the ends of a double channel-iron cross-arm, approximately 7 ft. in length, the sides of the triangle being 6 ft. The insulators used were 12 in. high and 14 in. in diameter. These insulators were cemented directly on cast-iron pins. The pins for the top insulators were made to screw on the 3-in. pipe; those for the side insulators had a square shank and were secured to the cross-arm by two $\frac{5}{8}$-in. bolts. The conductors were 19-strand, hard-drawn copper cable, equivalent to No. 1 B. &. S. solid copper wire. There were no wooden pins or cross-arms used on the towers. For protection against the line voltage as well as any high voltages due to lightning discharges, dependence was placed entirely on the insulators.

The ordinary length of span was 440 ft., but there were several spans of 1200 ft. and one of approximately 1600 ft. The line was designed for 60,000 volts at the generating end and

51,000 at the receiving end. The length of the line was approximately 101 miles.

The line is tapped at Irapuato, approximately 75 miles from the generating station and 26 miles from Guanajuato. At this point there is a sub-station where lightning-arresters of the usual station type are installed to protect the step-down transformers. From this it will be seen that there is a chance for the line to discharge at this point as well as over the arresters at either end of the transmission line.

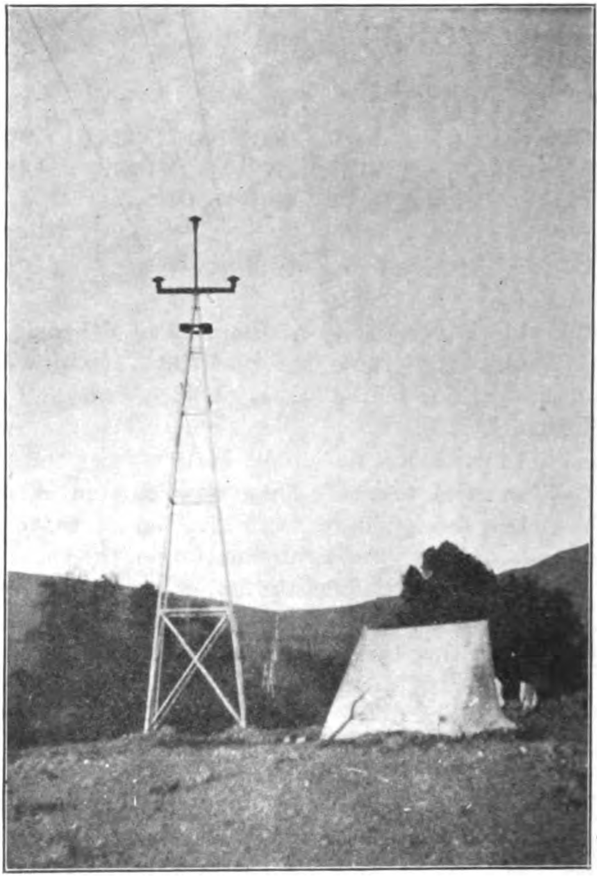

Fig. 1—Showing line as originally constructed

Thus far there have been three rainy seasons, which in the part of Mexico where the line is situated, generally last from

June until October. Heavy thunder storms come up nearly every day during July and August, and there is a storm on an average of every two days through a period of four months. During the rainy season of 1904, there was considerable trouble with lightning; the next season there was less, and during the rainy season of 1906, comparatively little trouble was experienced. The nature of the troubles, the expedients tried to overcome them, and the provisions for overcoming future lightning troubles, will now be considered.

The rainy season of 1904 came on with great severity in April, two months earlier than usual, and lasted until October. The injury to the transmission line from lightning was mostly confined to the puncturing of the top insulators by direct bolts of lightning, and in most cases a hole was bored through the top insulator nearly in a vertical line to the pin. These holes were approximately one inch in diameter and the sides were glazed. Usually, the insulators were badly shattered, but on putting the parts together one could generally find the glazed hole above referred to. Some side insulators were lost, but they were almost invariably injured at the time when the top insulators on the same, or adjacent, towers were injured. The side insulators were never punctured from the top in a vertical direction, but in some cases they showed a small puncture in a horizontal direction from the tie-wire to the pin. In nine cases out of ten, however, they were not punctured at all; but half of the top and portions of one or both petticoats on the same side were broken, presumably by the power current following lightning discharges over their surfaces.

As the principal trouble apparently came from direct bolts of lightning striking the top insulators, it was thought advisable to erect lightning-rods on the towers on the section of the line where most trouble had occurred. At that time the placing of a grounded cable over the transmission wires was discussed, but as this could not be done before the end of the rainy season, for suitable material could not be obtained in Mexico, it was decided to put up lightning-rods and get the benefit of experience with them during the rainy season then in progress.

Lightning-rods were erected in pairs, starting from the 3-in. pipe at the point where the cross-arm in pairs was attached, and projecting up on either side of this pipe to a distance of 6 ft. above the top insulator, at an angle of about 30 degrees from the vertical.

By the middle of August one-half of the line giving the most trouble was equipped with lightning-rods, and there had been erected quite a few rods on towers that were considered as being particularly exposed to danger from lightning. After the erection of these rods the difficulties were very much less, although there was still some trouble on the section of the line where they were in place. In no case were top insulators punctured through from the top as on the towers where rods

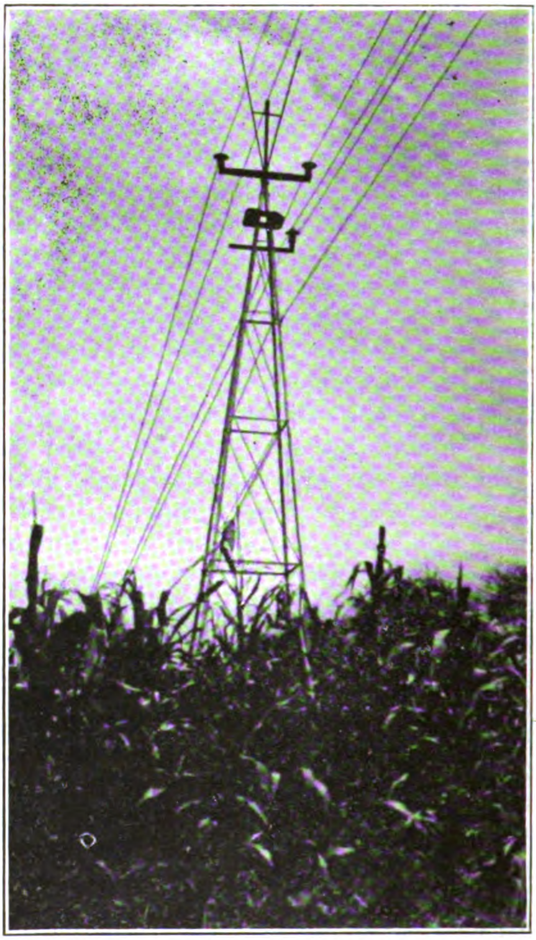

FIG. 2—Showing first change. Top insulator lowered, grounded cable in place, and lightning-rods left in position

were not in place, but when insulators were injured they usually had a part of the top and a petticoat broken on the same side. There were also a few cases where insulators were punctured in a horizontal direction from the tie-wire to the pin. During one very severe storm, eight insulators were broken on seven towers spread out over a distance of 14 towers. As the towers were spaced 12 to the mile it is improbable that the same discharge of lightning could have caused all of this trouble, unless it was transmitted over the power lines. Of the eight insulators injured none was punctured; they were apparently damaged by the current going over their side. Although these insulators were badly injured, the service on them was continued, but at a slightly reduced voltage.

One quite remarkable case happened in the Guanajuato sub-station, due, perhaps, to a bolt of lightning striking the line about a mile away. One of the men was standing in a balcony in Guanajuato watching the lightning display, when apparently a very heavy discharge struck the tower line, located over a hill just out of sight. At the same moment the lights in the room went out, showing that the service had been interrupted. The lightning which caused this interruption of service came into the sub-station over the top wire and jumped 4.5 ft. through air to ground, at the same time going to ground over the lightning-arresters. An insulator over which the arc formed in the sub-station had half of the top cracked off, but no injury was done to the transformers or other equipment. The towers were carefully examined near where the lightning was seen to fall, but there were no broken insulators or other evidence to show that the bolt had struck the line. However, as lightning had been previously seen to strike the towers without causing trouble, it was thought that a bolt of lightning had struck the tower line, a portion of this discharge coming over the wires into the sub-station. At the place where the bolt was supposed to have struck; the towers, on exposed places, were equipped with lightning-rods.

These cases are cited to show that insulators at a distance from heavy discharges of lightning may be subjected to very severe voltages, and, from all the data at hand, it is believed that the lightning-rods were efficient in protecting the insulators from direct bolts of lightning, and that the trouble that was still present on the section of the line equipped with lightning-rods was due to discharges traveling along the transmission wires.

During the season of 1904, the line troubles were quite evenly distributed over the first 50 miles of line out of the generating station. There were only two cases of trouble outside of this section that caused injury to the line insulators. Equipping this section with lightning-rods was begun in June and finished in August. This section of the line, except for a stretch of 15 miles, was left as equipped in August, 1904, until October 1906, or through more than two lightning seasons. As there was less trouble on this section of the line during these two seasons than during a portion of the lightning season of 1904, it is evident that the lightning-rods were at least partly effective.

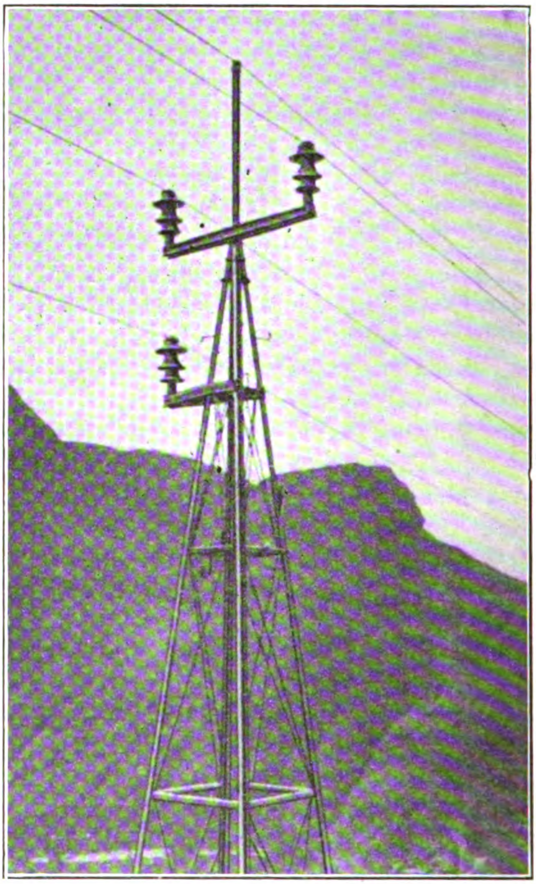

Fig. 3—Showing present appearance of line. Lightning-rods removed.

After finding that lightning-rods were not a complete protection, it was decided to make the experiment of lowering the top wire and putting up a grounded cable in its place. However, on account of delay in receiving material, very little was accomplished in time for the rainy season of 1905 and the experience with lightning during that season, was the same as that obtained during the rainy season of the previous year, except that there was much less trouble.

In the winter of 1905-1906, it was decided to install larger insulators on the tower line, and at the same time to lower all of the top cable to a position below one of the original side insulators. On the highest point of the tower, in place of the top transmission cable, it was decided to string over the entire line a ½-in., 7-strand, steel cable, grounded at each tower. Insulators 17½ in. in diameter, 20 in. high, were adopted for the first 60 miles of line out of the generating station, and the same insulator with a 14-in. top for the other 40 miles of line. It was unfortunate that the insulators with the 17½-in. top were not ready, so as to complete the line changes in time for the rains, but half of the line out of the Guanajuato sub-station was finished before the time for severe lightning storms had arrived. The other half of the line had been equipped the first year with lightning-rods, which were still in place, the top cable being in its original position on this section, except for a distance of 15 miles.

During the rainy season of 1906, the transformers were connected in star on the high-tension side, the center of the star being grounded; and in order to detect instantly when there was a ground on the line, a series transformer was put into this grounded line and the secondary leads carried to the switchboard, where an ammeter was connected to them. With this arrangement, when an insulator broke down, or the power current followed the lightning over the insulator, the station operator could tell when there was a ground on the line; and by shutting down at once he was able to prevent the burning off of the transmission wire. Usually when a ground appeared and the power was cut off, the line was found in good condition on again starting up.

There was no apparent trouble from lightning during the rainy season of 1906, on the section where the grounded cable was in place. On several occasions grounds came on the lines during lightning storms, and the power was immediately cut off in order to clear them. In general, these grounds could not be located, so it cannot be said that lightning did not go over the surface of the insulators on the section where the grounded cable was in place. The section where there was no grounded cable in place, but where the lightning-rods were erected, still gave some trouble, but the total amount was much less than in any preceding year.

The part of the line found to be the hardest to protect during all three rainy seasons was the middle of the 75-mile section from the generating station to Irapuato; in other words, the part of the line farthest from the location of lightning-arresters. This would indicate that arresters for discharging the line, located say every 25 miles, would be a valuable protection.

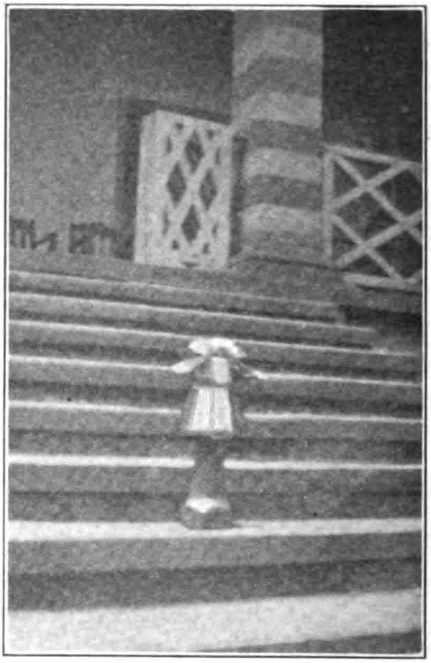

FIG. 4—Insulator perforated and broken by lightning bolt

The experience of the last three seasons prompts the writer to offer the following suggestions:

1. Insulators should not be disposed upon poles or towers so that they will be in the path of bolts of lightning going to ground by the supporting structure.

2. A grounded cable strung above the transmission wires at the highest point of the tower, is certainly more effective than lightning-rods in protecting the insulators and conductors from direct bolts of lightning.

3. Lightning-arresters for discharging the line in case very high voltages are present on the wires, would be of some value if located along the line at frequent intervals.

4. On steel construction, an insulator should be used that has a high margin of safety against puncture and arcing over.

It seems at present general practice to use insulators for high potentials with practically no margin of safety, and when the conditions are severe there is almost sure to be trouble. Aside from trouble with the puncturing of line insulators by direct bolts of lightning, which was apparently prevented by the use of lightning-rods on towers, nearly, if not quite all, of the trouble on this line has come from the breaking down of insulators by the current going over their sides, or through them, from tie-wire to pin. The writer ventures to assert that if the insulators had been much better, there would have been little trouble on the line where the lightning-rods were in place. Moreover, as a grounded cable undoubtedly affords better protection than lightning-rods, with a suitable grounded cable strung over the transmission wires, and better insulators, so disposed as to be out of the path of direct bolts of lightning, even without the installation of lightning-arresters along the line there would result a line that should be practically free from lightning troubles.

Note.—While personal experience suggests that the use, on iron construction, of insulators with a high factor of safety will greatly reduce troubles from lightning, it was decided to change our line insulators on account of trouble from an entirely different cause. During some months of the year the insulators become covered with condensed moisture just at sunrise, due to a very sudden rise in temperature, from the temperature of about zero centigrade. This often left insulators on the portion of the line where the temperature variation was most severe, covered with condensed moisture nearly as heavy as hoar-frost; and during the few moments when this effect lasted, the power current was apt to arc over the surfaces of the insulators. The old insulators were considered by the company's engineers as the best obtainable in 1902, and the insulators decided upon in January, 1906, were the largest commercial insulators on the market. A very much better insulator was desired, but for want of time to develop something better it was necessary to adopt an insulator with a factor of safety somewhat lower than that intended to be used. The apparent freedom from lightning trouble on the part of the line equipped with larger insulators and grounded conductor is due perhaps as much to the use of better insulators as to the grounded cable.

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26, 1907.

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LOCATION OF BROKEN INSULATORS AND OTHER TRANSMISSION LINE TROUBLES.

BY L. C. NICHOLSON.

Injury to a single insulator, under certain conditions of operation, renders an entire transmission line, many miles in length, entirely inoperative until the faulty insulator be discovered and replaced. The longer the line the more difficult it becomes to find a broken insulator, or to locate other irregularities in operating conditions, and a correspondingly long time is consumed in restoring the line to service.

When long lines are sectionalized by disconnecting-switches spaced at regular intervals, it is possible, by successive applications of voltage to section after section, to determine the particular section which contains the fault, and then to locate the exact point of failure by patroling a considerable length of line. This process is tedious on account of the necessity of manipulating the line-switches upon telephonic advice from the generating station, and by reason of the time required to patrol the particular section containing the fault. For these reasons it is desirable to employ some method of locating faults by means of electrical measurements which shall be capable of a reasonable degree of accuracy, and of being performed in a short time.

There are several well-known methods of locating faults electrically; among these are the Varley and Murray loop tests. These and other ordinary methods operate with low-voltage direct current acting upon a Wheatstone bridge arrangement of resistances and galvonometer, and are readily applied to metallic circuits suffering from a total grounding or short-circuit. If, however, the fault be a partial one, such for instance as occurs on a high-voltage transmission system when an insulator becomes defective by puncture, or otherwise, it is impracticable to apply any of these methods, since a high voltage must act to develop any current-flow under these conditions. It is manifestly impracticable to manipulate adjustable resistances quickly and accurately in a high-voltage circuit, or to use direct-current instruments such as a galvonometer, because alternating current is demanded by the relatively high voltage which it is necessary to employ. It will be appreciated that for a fault-locating method to be trustworthy, it must be adapted to the normal operating potential of the transmission line, inasmuch as partial faults sometimes develop which will withstand normal voltage for a short time. It is therefore essential and also desirable to employ the generating, transforming, and switchboard apparatus of the generating station for making fault-location tests upon the transmission lines. A simple scheme of connections involving the manipulation of a few hook-switches has been employed for this purpose upon a long-distance high-voltage circuit, and it has been found possible to locate quickly and accurately any fault seriously interfering with operation.

The particular plant upon which such a test has been operated transmits power at 60,000 volts, 25 cycles, three phase, over lines approximately 160 miles long. The line conductors are of aluminum, spaced seven feet apart, and are carried partly on steel towers and partly on wooden structures. In both cases the insulators are supported on electrically grounded steel pins, a ground-wire being used for this purpose on the wooden structures. The step-up sending transformers operate delta-star with neutral grounded. Under these conditions of operation and line construction, it is evident that an insulator becoming disabled flashes and holds an arc between the line conductor and the insulator pin, which constitutes a short-circuit on one of the transformers and prohibits further service until the injured insulator be replaced. Causes other than broken insulators may interfere with operation; for example, branches of trees fouling wires during wind storms, or even malicious interference. However, trouble necessarily appears from one wire to earth, or from wire to wire.

The method of locating faults referred to above, consists in supplying current from a generator and transformer to the fault to earth through a divided circuit or a loop, formed by joining two line conductors together at both ends, one of the wires so connected containing the broken insulator to be located. The total current supplied, divides quantitatively between the branches of the loop in a proportion depending upon the ratio of the two impedances to the fault which ratio is determined by, and therefore is determinative of, the location of the fault. Indicating ammeters or integrating wattmeters connected in the two branches of the loop by means of proper transformers show the current or power supplied through the respective conductors. Amperes or watts so measured, together with the known electrical constants of the line under test, serve to determine the geographical location of the fault. Evidently, only the relative currents flowing in the two paths at the same instant, or the relative integrated power delivered during any length of time, need be ascertained.

Fig. 1 shows the scheme of connections which has been employed. The loop consists of wires *A* and *B* which have a metallic short circuit placed on them at the generating station just inside the current transformers, and a similar one at the receiving station just outside the disconnecting switches. It is, of course, necessary for the generating station operator to order a short circuit placed on the proper wires at the distant end of the line when a test is to be made. *E* is the high-tension winding of a power transformer. Its connection to earth is through the neutral which operates grounded. The particular transformer used will depend upon which wire is in distress. *R* is a limiting resistance connected in series with the loop, and is designed to limit the total flow of current to the capacity of the transformer and the measuring instruments. At *V* is represented a fault to earth, which usually takes the form of a broken insulator, over the surface of which current flows through an

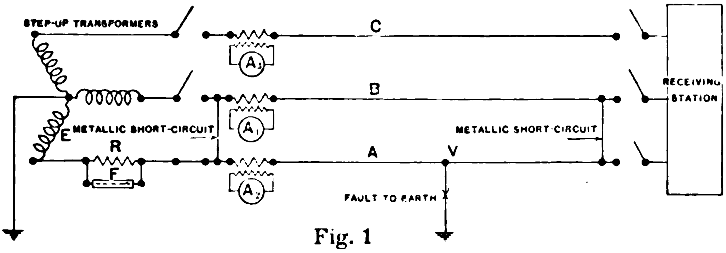

Fig. 1
SCHEME OF CONNECTIONS.

arc. A_1, A_2, A_3 represent indicating ammeters in the secondaries of current transformers.

The limiting resistance R may be connected in either the high- or low-tension side of the transformers. The amount of resistance used, depends largely upon the character of the fault to be located. It must be large enough properly to limit the current flow, and must not be so high that it will interfere with a continuous flow of current through an arc after the fault has developed. Moreover, when testing for a fault which will resist nearly normal voltage, on a long transmission line taking a large charging current, there occurs a loss of potential across this resistance on account of the charging current flowing through it, so that the potential operating upon the fault may be less than normal potential of the system and too low to flash over the injured insulator. To obviate the necessity, under such conditions of raising the voltage of the system above normal, an expulsion fuse, F, shunting this limiting resistance has been employed. The capacity of this fuse must be at least equal to the normal charging current of the line. Its use ensures full voltage at the fault and allows the current flow to be properly controlled by the resistance R after the fault has developed and the fuse has burned. Any automatic overload circuit-breaker could be substituted for the fuse.

Since the resistance drop is in quadrature with the condensance voltage, a fuse or its equivalent is necessary only when testing long lines, and then very rarely.

A cheap and entirely satisfactory form of resistance, well adapted to use in the high-tension circuit, consists of ordinary cement concrete columns supplied with expanded-metal terminals. Four columns, 12 ft. long, a square foot in section, each having a resistance cold of about 2000 ohms, have been used in multiple or singly as occasion demanded. The temperature-resistance coefficient of concrete being large and negative, it is an easy matter to arrive at a proper resistance by heating the columns with current. Such flexibility in this resistance has at times proved very convenient.

Experience so far obtained, indicates that in a large majority of insulator failures, a 1,000-ohm concrete resistance in the high-tension side does not prevent flashing of a broken insulator, nor does it interfere with satisfactory current readings. Occasions do arise when the fuse is necessary, and when a comparatively low resistance must be used to maintain an arc at the fault long enough to obtain current readings on indicating ammeters. It appears that after an arc has once been established it will hold indefinitely, provided the current flow be not too restricted. The more incomplete the fault and the longer the striking distance, the larger the current required. From 50 to 100 amperes has proved an appropriate range of current for general testing purposes. Variations that occur when using this amount of current are usually gradual—being due to decreasing resistance of the concrete—so that there is rarely any difficulty experienced in obtaining satisfactory simultaneous ammeter readings during a period of, say, five or ten seconds.

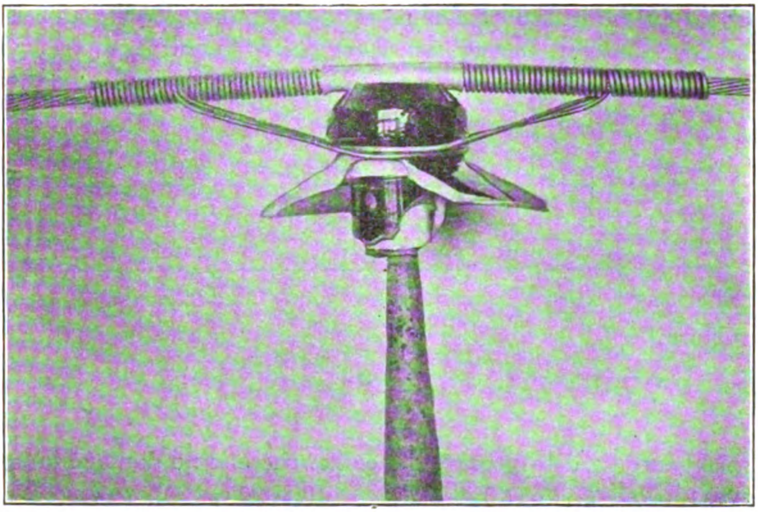

FIG. 2.

On account of conditions at the fault being unfavorable to a steady flow of current, trouble may be had in reading indicating instruments which are not dead-beat. In such cases integrating wattmeters may be resorted to, to obtain a comparison between the power supplied to the fault through the two sides of a loop. Only in extreme cases, such for example as disturbances caused by swinging tie-wires or tree branches, is it necessary to use wattmeters.

Fig. 2 shows an insulator broken by a stone in such manner that it withstood operating potential for a few seconds, the striking distance being about seven inches. This insulator was located easily with ammeters which were not dead-beat.

The effect of an arc upon the cable is an important consideration. If it is burned so as to require splicing, considerably more time is consumed in restoring the line to service than if only a broken insulator is to be replaced. This is particularly true with long spans, on account of the weight of the cable to be handled. Under ordinary operating conditions it is impossible to know how much the cable is burned by the short-circuit current at breakdown and how much by the testing current. Damage to the cable by an arc carrying 100 amperes sustained forty seconds has been found to be insignificant when the striking distance is several inches. It appears that there is some damage if the arc is short and confined, such as would obtain in the case of an insulator punctured through the head. However, during the short period required to read the instruments, the cable does not suffer materially. Where shields are used to protect the cable, there is no damage in any event.

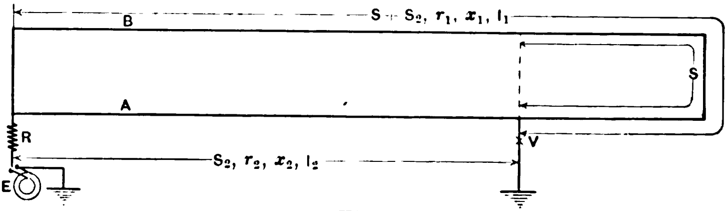

Fig. 3

Since the current through the faulty conductor varies from one half the total current when the fault is at the distant end of the line to the total current when the fault is at the testing station, while the current through the other conductor varies from one-half the total current to zero corresponding to the same locations, it is desirable that the full-scale value of one ammeter should be twice that of the other. For this reason, and on account of their superior accuracy, portable instruments are preferable to the switchboard type.

Referring more particularly to the division of current between the two paths, it has been found that this division takes place in accordance with Ohm's law, or that the currents I_1, I_2 are inversely proportional to the ohmic resistances r_1, r_2 of the two branches.

Assuming the resistance volts of the two branches equal, it is interesting to note how reactance volts are also equal. The two parallel wires constituting the loop, Fig. 3, carry currents in the same direction to the fault, and in opposite directions beyond it. These currents, I_1, I_2, are of the same phase and frequency but of different magnitude, I_2 being larger than I_1. Only that magnetic flux included between the wires need be considered as influencing a division of current, inasmuch as the flux which embraces both wires affects only the total impedance of the entire circuit. The flux included between the wires up to the fault is the resultant of two oppositely acting magnetomotive forces separated in space by the distance between centers of wires. The flux density at any point within either wire is proportional to the current and to the distance from the center, while at any outside point it is proportional to the current but inversely proportional to the distance from the center.

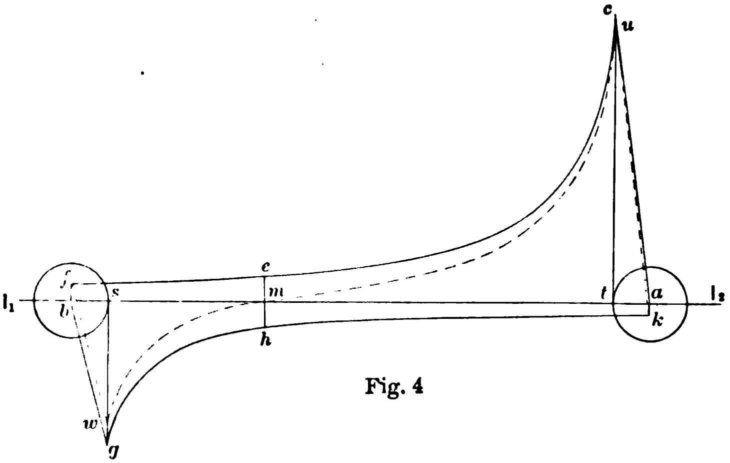

Fig. 4

Fig. 4 is a graphical representation of magnetic conditions existing at any instant. Area $a\ c\ f\ b$ represents flux due to I_2 and area $b\ g\ k\ a$ that due to I_1, I_2 being in this case twice as large as I_1. At m, a point situated so that $\frac{am}{bm} = \frac{I_2}{I_1}$, there is a complete cancellation of magnetomotive forces. If the two currents are in phase, this point remains one of zero flux, and the resultant flux on either side of it caused by the difference between the two magnetomotive forces is that influencing the current flow in the corresponding wires. This resultant, represented, by the dotted line *k u m w f* obtains through a distance S_2, Fig. 3, while the flux in the loop beyond the fault, represented by the area *b g k a*, obtains through a distance S.

So that,

$$\frac{X_2 I_2}{X_1 I_1} = \frac{I_2 S_2 \left(0.25 + \log_\epsilon \frac{d}{r} \cdot \frac{I_2}{I_1 + I_2}\right) - I_1 S_2 \log_\epsilon \frac{I_1 + I_2}{I_1}}{I_1 S_2 \left(0.25 + \log_\epsilon \frac{d}{r} \cdot \frac{I_1}{I_1 + I_2}\right) - I_2 S_2 \log_\epsilon \frac{I_1 I_2}{I_2} + I_1 S \left(0.25 + \log_\epsilon \frac{d}{r}\right)} \qquad (1)$$

where, d = distance between wires

r = radius of wire

Assume,

$$\frac{S_2 + S}{S_2} = \frac{r_1}{r_2} = \frac{I_2}{I_1} \qquad (2)$$

$$S = S_2 \left(\frac{I_2 - I_1}{I_1}\right)$$

$$I_1 S \left(0.25 + \log_\epsilon \frac{d}{r}\right) = I_2 S_2 \left(0.25 + \log_\epsilon \frac{d}{r}\right) - I_1 S_2 \left(0.25 + \log_\epsilon \frac{d}{r}\right) \qquad (3)$$

Substituting (3) in (1) and expanding, we have,

$$X_2 I_2 = X_1 I_1,$$

or the inductance drop is the same over each path. Since the total volts are identical, this result follows directly from equation (2), as does also the assumption that the two currents are in phase.

From a consideration of resistance only,

$$\frac{I_2 - I_1}{I_2 + I_1} = \frac{\frac{r_1 - r_2}{2}}{\frac{r_1 + r_2}{2}} = \frac{\text{ohms from fault to distant end of line}}{\text{total resistance of one wire}} \qquad (4)$$

Either (2) or (4) may be used to compute fault locations, The latter is less influenced by observation or instrument errors and lends itself more readily to graphic representation. If line-structure numbers of a given circuit, and the ratio $\frac{I_2-I_1}{I_2+I_1}$ be used as coordinates, a chart may be constructed, as Fig. 5, from which the fault location may be readily taken. This chart contains right lines drawn from the point $\frac{I_2-I_1}{I_2+I_1} = 1.00$ to the line-structure number at which the loop is closed. The use of such a chart makes it possible to test to any point along the line at which it may be convenient or desirable to place a short circuit, without the inconvenience of computing the resistance to that point. Such flexibility and ease of construction is not true of a chart based upon the relation between $\frac{I_2}{I_1}$ and the line structure at which the fault occurs, because this relation is hyperbolic.

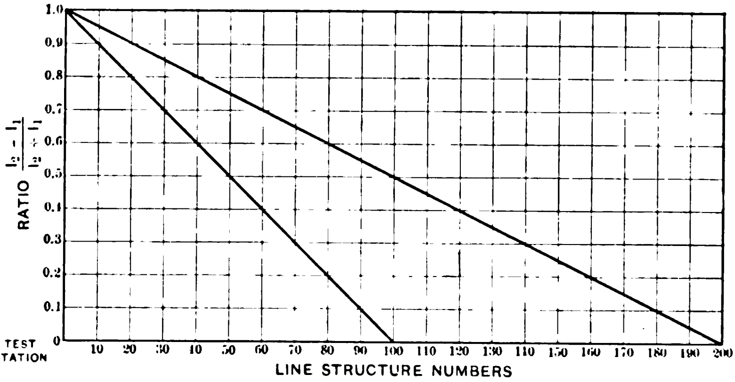

Fig. 5

When testing lines whose conductors are not of uniform cross-section throughout, the foregoing method is not applicable without modification. Whether large wires be followed by small ones, or the reverse, the current flow will not be determined by resistance only. If the wires are larger near the testing station than farther out, the effect is to locate the fault too far away; to locate it too near if small wires be followed by large ones. The reason for this is evident from a consideration of the relative impedance of the two branches of the loop. The branch having the larger ratio of inductance to resistance, of course takes relatively less current than that indicated by resistance. A comparison of inductances is rendered complex on account of the phase-displacement which takes place between the two currents by reason of the disparity between the ratios of inductance and resistance.

The error involved through considering resistance only is, however, a linear function of the distance from the distant end of the line to the fault, if it be in the region beyond the junction of the two sizes of the cable, and likewise, of the distance from the testing station if the fault be nearer than the junction point. Thus it is possible by making a single test upon a fault placed at the junction of the two sizes of wire, to obtain a correction which is applicable to the entire line. This correction is readily applied to the graphic chart mentioned above. It consists of right lines drawn from the experimentally determined value of, $\frac{I_2 - I_1}{I_2 + I_1}$ to either end of the resistance line. A maximum correction of five miles has been found necessary in the case of a line made up of 60 miles 0.75 in. aluminum cable followed by 70 miles of 0.52 in. cable when testing at 25 cycles per second.

The following are some of the results so far obtained in locating faults by the two-ammeter method:

Length of line	I_1	I_2	Computed location tower number	Actual location tower number	Error
118 miles	1.1	1.125	4472	4479	1000 ft.
118 "	1.53	1.55	4482	4481	200 "
36 "	1.56	2.4	512	513	500 "
23 "	0.4	4.5	151	153	1000 "
60 "	1.36	3.57	512	513	500 "
60 "	0.8	2.00	520	519	500 "
60 "	1.70	2.05	730	731	200 "

This list includes a variety of insulator failures. Some of them were complete grounds, while others withstood high voltage. In only one case was there any trouble in obtaining satisfactory ammeter readings—this being a loose wire swinging in a wind storm.

The time consumed by an experienced operator in making a test under ordinary conditions is about thirty minutes There is sometimes a delay on account of the necessity of communicating with the distant end of the line.

The test is subject to the following restrictions: when several faults are on a single wire they must be located in reverse order of their insulating values, and must be repaired in the order located; when all three wires are in trouble, the one having the highest insulation cannot be tested until one of the others is repaired; if two complete grounds a considerable distance apart occur on a single wire, the localizaton will be in serious error.

These conditions are for the most part exceptional, although entirely possible. None of them has presented itself since this method of testing has been in use.

A paper to be presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26, 1907

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ONE-PHASE HIGH-TENSION POWER TRANSMISSION.

BY E. J. YOUNG.

The recent advance in Europe of the Thury direct-current system of power transmission demonstrates the fact that unless an alternating-current system approaching it in simplicity of design and economy of material is developed, it is only a question of time before the high-tension direct current will gain a footing upon this continent. Consequently, the writer proposes a high-tension one-phase system having several desirable features not in common with either the direct-current or the three-phase system.

While the present three-phase system is more flexible than the direct current, it is more complicated, and requires a considerably greater outlay for transmission material. The ordinary one-phase system is simpler than either of these two, but requires 25% more copper than the three-phase system and a proportionately greater amount than direct current. Then again, considering the strain upon the insulators as a standard of comparison, the fundamental difference between direct- and alternating-current systems gives the former an advantage that no alternating-current system can overcome.

In Fig. 1 is shown a general outline of the proposed one-phase system. One-phase generating apparatus is supplying energy to step-up transformers—for convenience only one is indicated. The center of the high-tension windings is permanently grounded, thereby reducing the electromotive force from line to ground to one-half that between the line wires, and in so doing placing one-phase transmission at least on a par with three phase in the matter of economy of copper. At the receiving end the step-down apparatus is similar to that at the power station, the center of all high-tension windings being grounded. At the sub-station there is a motor-generator set consisting of a one-phase synchronous motor and a three-phase power and lighting generator. The set is started by an ordinary one-phase series motor operated by current from an autotransformer connected across the secondaries of the step-down transformers. The exciter may be on the motor-generator shaft as in Fig. 1, or operated by a separate motor, as best suits the conditions.

An example will probably serve to illustrate the comparison between the different systems, especially those by alternating current. Therefore it is proposed to transmit 15,000 kw., 100 miles with 10% loss. The electromotive force to be 50 kilovolts from line to ground at the receiving end, and the alternating-current frequency to be 30 cycles. The following conditions for the three-phase line are assumed:

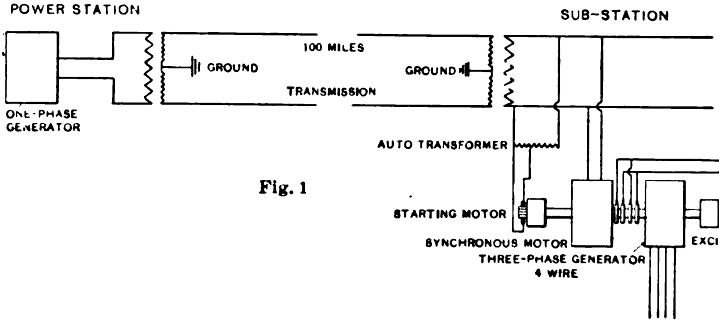

Fig. 1

Power-factor = 0.9.
Star-connected transformers with grounded neutral.
Electromotive force to ground = 50 kilovolts.
Electromotive force across line = 50 × 1.732 kilovolts.
By transmission formulas the copper section per line will be:

$$1. \qquad \text{Cir. mils} = \frac{D \times W \times K}{P \times E^2} \text{ in which}$$

$D = 100 \times 5280 \times 1.02$ ft., 2% allowed for sag in conductors, etc.
$W =$ 15,000,000 watts.
$K =$ 1330 for 0.9 power-factor, three phase.
$P =$ 10% loss.
$E = 50 \times 1.732$ kilovolts.

Consequently:

$$2.\quad \text{Cir. mils} = \frac{100 \times 5280 \times 1.02 \times 15,000,000 \times 1330}{10 \times (50,000 \times 1.732)^2} = 143,270.$$

$$\text{Weight of copper per mile of line} = \frac{143,270 \times 3}{62.5} = 6876 \text{ lb.}$$

As shown in Fig. 1, the center of the high-tension windings is grounded. The electromotive force of the one-phase system may therefore be double that to ground and still retain the same strain upon the insulators as in the three-phase system. One-phase conditions:

Electromotive force..........100 kilovolts.
Power-factor........0.9
Constant K........2660 for 0.9 power-factor, one phase.

Therefore:

$$3.\quad \text{Cir. mils} = \frac{100 \times 5280 \times 1.02 \times 15,000,000 \times 2660}{10 \times 100,000^2} = 214,890.$$

$$\text{Weight of copper per mile of line} = \frac{214,890 \times 2}{62.5} = 6876 \text{ lb.}$$

In order that the direct-current system shall be under the same conditions as the alternating current, the electromotive force to ground will be 50 ÷ 0.707 or approximately 70.7 kilovolts. This will give practically the same strain on the insulators as would 50 kilovolts alternating current. By grounding the row of generators at the power and receiving stations, as proposed on the direct-current transmission from Monthoux to Paris, France, we have a potential of 141.4 kilovolts between line wires.

According to formula 3, with K equal to 2160 for direct-current, all other factors remaining the same, we obtain:

$$4.\quad \text{Cir. mils} = \frac{100 \times 5280 \times 1.02 \times 15,000,000 \times 2160}{10 \times 141,400^2} = 87,270.$$

$$\text{Weight of copper per mile of line} = \frac{87,270 \times 2}{62.5} = 2792 \text{ lb.}$$

Comparing these results we find that as far as transmission material is concerned, the direct-current system is far more economical than either the three-phase or the one-phase system.

There is practically no choice between the latter two. Therefore, any advantage the alternating-current system may have, must necessarily be in the power house and the sub-station.

Comparing now the three phase and one phase with a view of estimating the probable saving the latter would represent in line material. On the one-phase system there would be at least 12 less insulators and pins per mile if steel towers were used, and 44 on ordinary pole construction. At $2.50 per pin and insulator, this would mean an initial saving of $30, or $110 a mile for pins and insulators alone. The cross-arms, etc. of the one-phase line would probably be longer and heavier than those of the three-phase line on account of the wires being farther apart, due to higher electromotive force, but this is more than compensated for by the poles being about 5 ft. shorter, since the upper wire is done away with. There is also the difference in cost in stringing wires—three wires on one system and only two on the other.

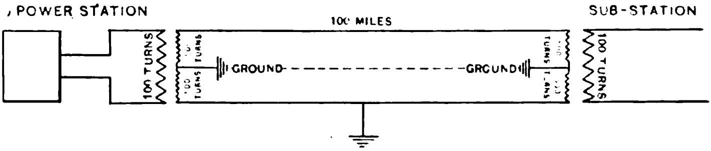

Fig. 2

One of the most important advantages of the proposed system, with reference to continuity of service in case of trouble on transmission line, is shown in Figs. 2, 3, and 4. In Fig. 2 the line is supposed to be grounded. The number of turns in the transformer windings is indicated in order to illustrate the effect of such an occurrence. With independent automatic circuit-breakers in each high-tension line at the power house and sub-stations—those at the power house operated by over-load time-limit relays, and the sub-stations supplied with reverse-current relays operating with practically no time-limit—the affected line will be cleared by the short circuit.

We have now a 50-kilovolt transmission in which the ground serves as one conductor. At the receiving end the ratio of transformation is doubled, but at the same time the electromotive force is reduced one-half. Consequently, the secondary potential will not be altered by one line being cut out of circuit on account of trouble or for repairs and inspection. In order to raise the system to approximately its original capacity, the high-tension windings, being in two sections, are connected as in Fig. 3.

Upon removing the trouble and connecting the transformers as in Figs. 1 and 2 it would appear that, by simply closing the switches upon the repaired line, normal operating conditions are resumed. Although this last operation might result in conditions that could only be learned by experience, the illustration will show that as long as one line remains upon the insulators the service will neither be interrupted nor the transmitting power of the line very much reduced. In the event of the above trouble occurring upon the three-phase or direct-current lines, the effect is different. With three phase the entire system will be interrupted; with direct current, one half the motor-generators will stop. It will therefore be seen that the necessity of a duplicate line is much less needed on one phase than on either of the other systems.

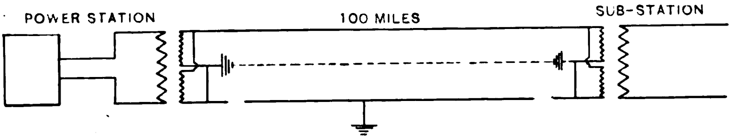

Fig. 3

Owing to the high electromotive force of the alternating-current system the space occupied by the high-tension bus-bars etc. as ordinarily installed would represent a considerable portion of the station. Consequently, a diagram of the station distribution, requiring small space but giving ample insulation, the high-tension lines being under oil, is shown in Fig. 4; although applicable to three-phase or one-phase, it will obviously present less complications when used with the latter.

In Fig 4 are shown four independent transformer units placed in a single case partioned into four chambers. Each chamber contains a transformer, the switches necessary for its operation, and the interconnecting bus-bars between adjacent transformers. The lines *C* and *D* lead to low-tension generator bus-bars; *A* and *B* lead to high-tension line-switches which are controlled by overload relays; four lines, that is, *A* and *B*, being necessary in order to facilitate inspection or repairs of individual transformers while others are in operation. It will be seen that any transformer may be cut out of circuit from adjacent units by the disconnecting switches S, which, under normal operating conditions are all closed; S_1 and S_2 indicate double-pole double-throw remote-control switches for connecting the high-tension coils either in series across A and B or, in the event of trouble on one line, in parallel from ground G to the unaffected line.

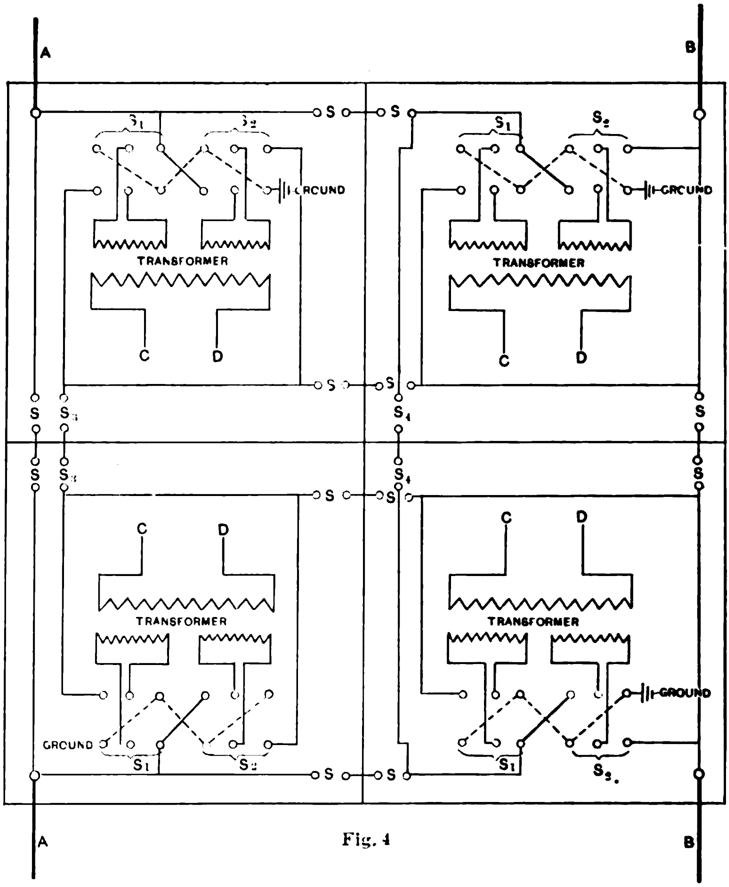

Fig. 4

The interconnecting switches S_3 and S_4 connect the bus-bars in different chambers. Under ordinary operating conditions all transformer switches S_1 and S_2 would be thrown to the right, thus putting the high-tension windings in series. In the event of line A being cut out, all switches, S_1, could be thrown to the left there by placing the two windings in multiple from B to ground G;

if line B is disconnected, all switches, S^1, would be to the right and S_2 to the left. Since the cooling coils have been dispensed with, the intention is to place the entire case in a pit surrounded by running water, or to have the oil withdrawn from case and cooled externally as is proposed in certain transmission plants.

Notwithstanding all that has been said in favor of the one-phase system it has several disadvantages. In the first place the generating apparatus costs more than three-phase, but less than direct-current apparatus. The inability of operating large induction motors is also a serious disadvantage which would necessitate the use of motor-generators in many cases. Then again, there might be greater liability of surges in the one-phase circuit due to the larger current carried by them, but the troubles accompanying star-connected transformers, as explained by Mr. J. S. Peck, are entirely eliminated. The number of transformers upon the system, as shown in Fig. 4, will be much less with one phase, and the entire switching apparatus is not only reduced but also greatly simplified.

In the preceding suppositions the writer appreciates the fact that a number of factors which would enter into the design of a transmission system of such length and capacity have not been considered, the case taken being simply to illustrate a general theory of the proposed system. On comparatively short transmissions, the disadvantages of one-phase operation and distribution would no doubt counterbalance any advantage it presents. However, where very long lines are contemplated, such as the 250-mile line in France, or electrifying railway systems in this country, one phase is not only the simplest, but unites maximum reliability of service with a minimum number of transmission wires.

A paper to be presented at the 24th Annual Convention of the American Institute of Elctrical Engineers, Niagara Falls, N. Y., June 28, 1907.

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SOME POWER TRANSMISSION ECONOMICS.

BY FRANK G. BAUM.

In designing power transmission systems, it is always well to bear in mind that the ultimate development of the art and of the country has not yet been reached.

In the early days of railroading, the roads and equipment were not of the present trunk-line standard. Light rails, engines and cars, and unfenced right-of-way, and unballasted roadway sufficed. To construct at that time up to the present standard would have meant bankruptcy. Even now the manager or engineer who would build his branch lines of the same standard as his trunk lines, would invite a receiver to take charge of the road.

The same conditions hold true for power plants and transmission lines. The wise manager or engineer builds to meet existing conditions, looking into the future as far as he can. He can not afford to build duplicate plants and lines for every case, nor build all his lines on private rights-of-way, with steel towers and other refinements and safeguards. He can not afford to build a duplicate transmission line, at an additional interest cost of $5,000 per year, when the probability of an interruption, which will cause a loss of revenue of $500 per year, to a consumer, is extremely remote.

It may not be as difficult to determine the proper power station and line to build when unlimited capital and ideal power conditions exist as when there is restricted capital, limited revenue, and low-priced power at the consumer's end. Although in the latter case the amount of money to be expended may be much less than in the former, even more thought is demanded of the engineer; for, in the former case, having ample resources,

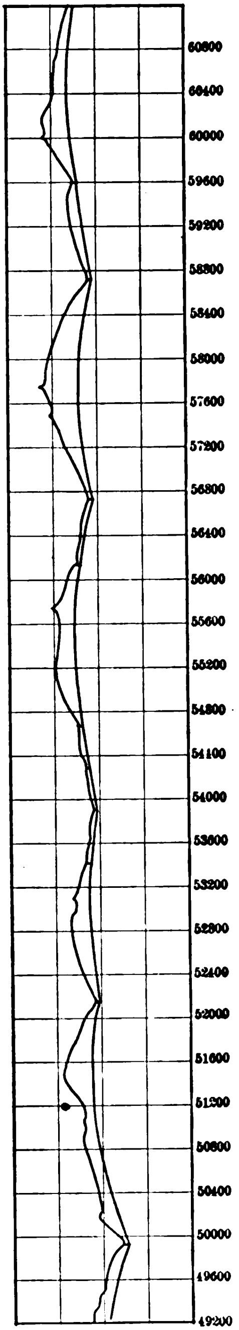

FIG. 1.—Profile of Mountain Pole Line. Distances in ft.

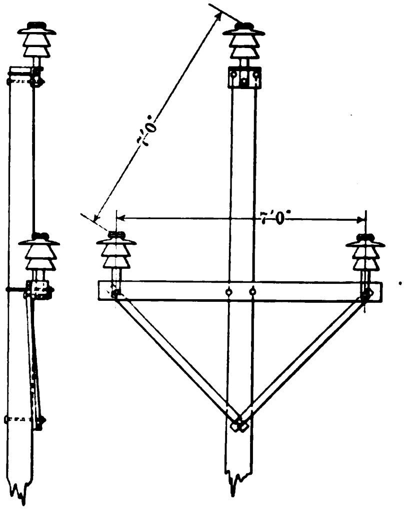

FIG. 2, Structure 1.—Spans up to 500 ft. 7-ft. triangle. Single construction. On corners, double arms and plates and one pin.

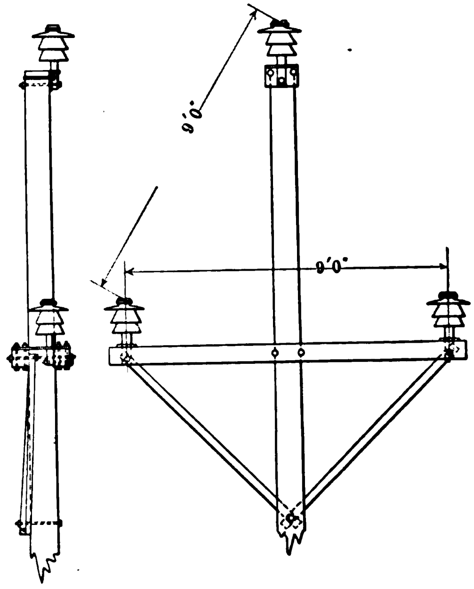

FIG. 2, Structure 2.—Spans 500 ft to 700 ft. 9-ft. triangle. Double arms and plates, one pin. On corners, double arms and plates and two pins.

he builds as best he can, while in the latter he must be a judge of conditions and see far ahead, in order that the line which he builds may earn money, and at the same time be capable of extension on some plan to meet the growing needs of the country and business.

To illustrate the necessity of doing things in inexpensive ways in the early development of an art, a business, or a country, some examples are given of the work done on the system of the California Gas and Electric Corporation. Along some of the lines where the load is small, one wire only is run to the sub-station, an inexpensive building, and one transformer, with ground return, is installed. One-phase motors are used. For larger stations, sometimes up to 500 kw., two wires are run to the sub-station and, by using ground return on the primary and open delta on the secondary, three-phase motors are operated.

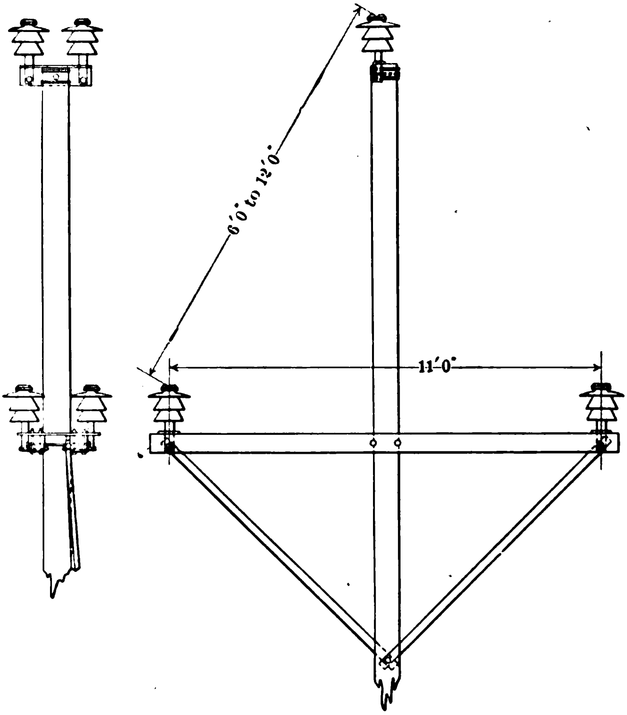

FIG. 2, Structure 3.—Spans 700 ft. to 900 ft. 11-ft. triangle. Double arms and plates and two pins. Corners special.

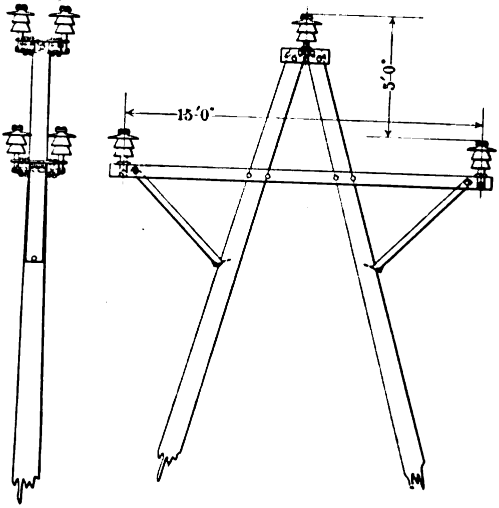

Fig. 2, Structure 4.—Spans over 900 ft. to 2000 ft. 16-ft structure. Double 6-in. by 6-in. arms, plates and two pins. Two-pole structure.

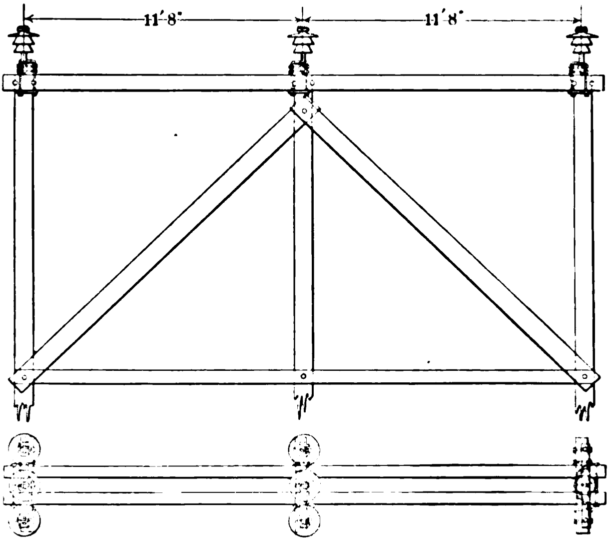

Fig. 2, Structure 5.—Spans 2000 ft. to 3000 ft. 24-ft. structure. Double 6-in. by 8-in. arms, plates, and three pins. Three-pole structure.

Loads as large as 1500 kw. have been carried to a distance of 100 miles on two transformers Y-connected on the primary, with grounded neutral, and open delta on the secondary. Neither the power consumer, nor the power-house operator has noted anything unusual.

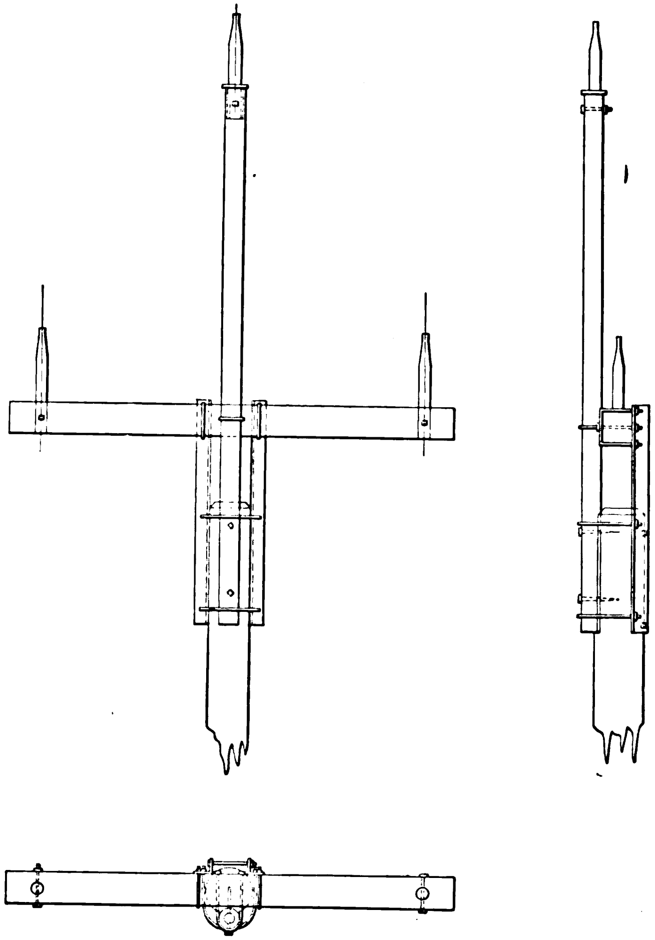

FIG. 3.—Pole-top extension.

For larger sub-stations a single three-phase transmission line supplies the load, even where the length is 50 miles or more. The consumer can not afford to pay for a duplicate line when the output per year of the factory is practically unaffected by interruptions. Interruptions amounting to one hour per month would be one-seventh of one per cent. of the total time, and the power company that has an average of an hours' interruption per month is certainly giving very bad service. It is evident that the construction of a duplicate pole-line for such service is entirely unwarranted.

As to the construction of pole-lines, it has been found that in some parts of the West where cedar poles may be purchased at a low price, this class of pole-lines is still the most economical, and everyone must admit that this type of construction has proved remarkably effective. Of course under certain conditions tower lines only would be considered, but two wooden pole lines entering a city by two different routes will give greater reliability than any two-circuit tower line that can be built. The cost of a two-circuit tower line would be as great as that of two pole lines. A line using tower construction requires a private right-of-way, and in a new country it may not be possible to pay from the earnings the interest on the increased cost of the right-of-way, as well as on the tower construction. The engineer, of course, always prefers the best construction, but he must consider the net revenue to be derived from an en-

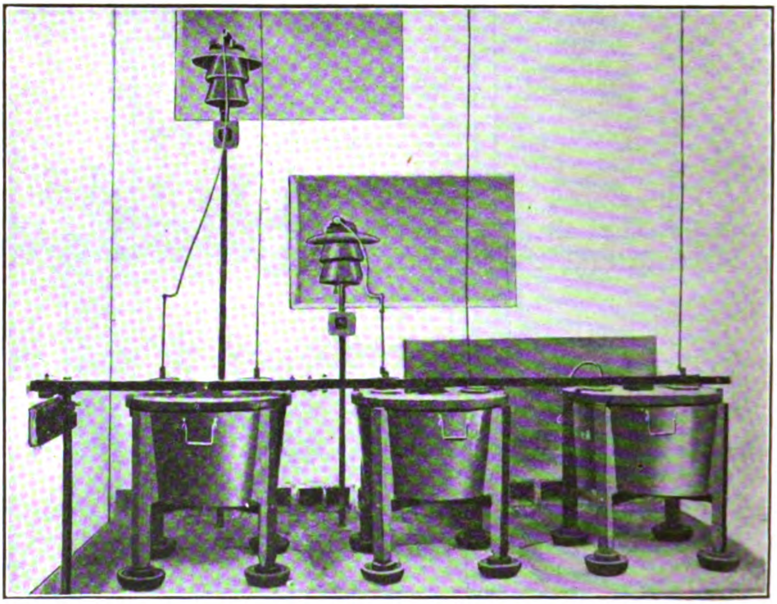

FIG. 4.—Early type oil-switch.

terprise in a given number of years. In mountain sections, the economies of line construction lie in the use of the hills for the structures and in using long spans. In some cases the amount saved in clearing, in poles, insulators, and labor will amount to 50%.

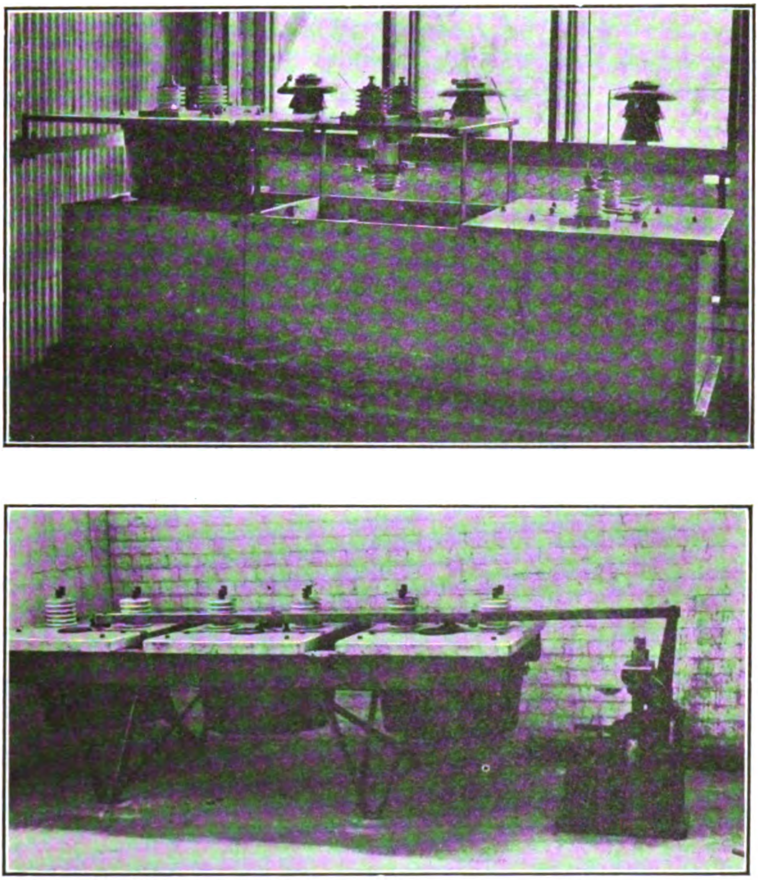

FIG. 5.—Later types of oil-switches.

Fig. 1 shows a profile of a line recently constructed, the middle section of which consists of a series of spans varying in length from 700 to 2700 ft. It will be seen that by taking advantage of the hills to form the greater part of the height of the structure great economy results. A span of 3000 ft., with an an allowable sag of 300 ft., would if on the level, require towers over 300-ft. high, while in this line on similar spans, simple wooden pole structures 30-ft. high are all that is necessary. The profile of a line of this kind is first determined, and the span-length and structures designed so that the wires clear the ground sufficiently. This gives an economical and satisfactory line.

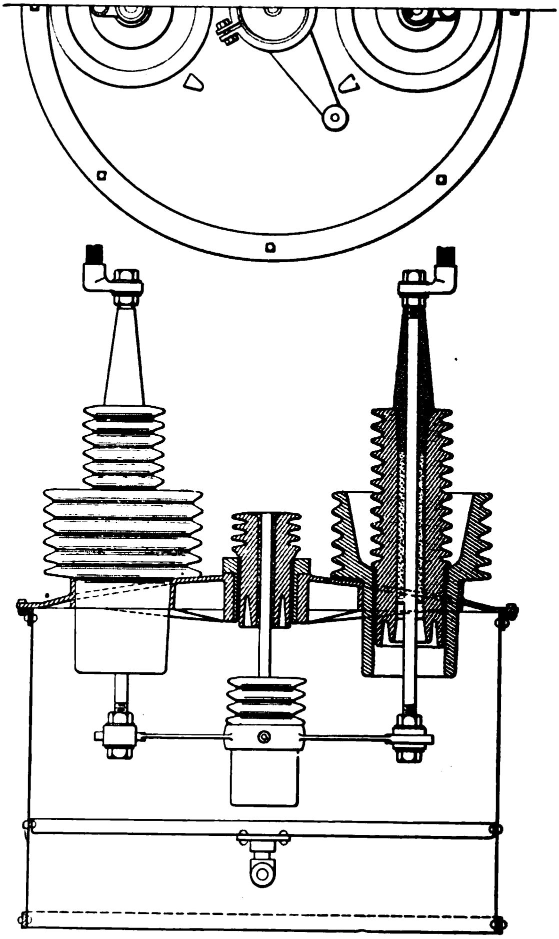

Fig. 6.—Modern type of oil-switch.

On long spans the wires are spread at the structures as shown. In addition, the top or middle wire is given 10 to 40 ft. less sag (depending on the span) than any of the others. One of the outside wires is also given 5 to 20 ft. less sag than the other.

In this way there is obtained a vertical separation at the middle of the span; and 10 ft. of vertical separation is better than 20 ft. of horizontal, because the wires then can not come together, even when acted upon by gusts of wind having a tendency to lift the wires. Spans greater than 2000 ft. are not installed except in certain cases where it can scarcely be avoided. Spans of 600 to 1500 ft. give the best line.

Fig. 2 shows standard types of pole structures used on some of the mountain lines recently constructed in California.

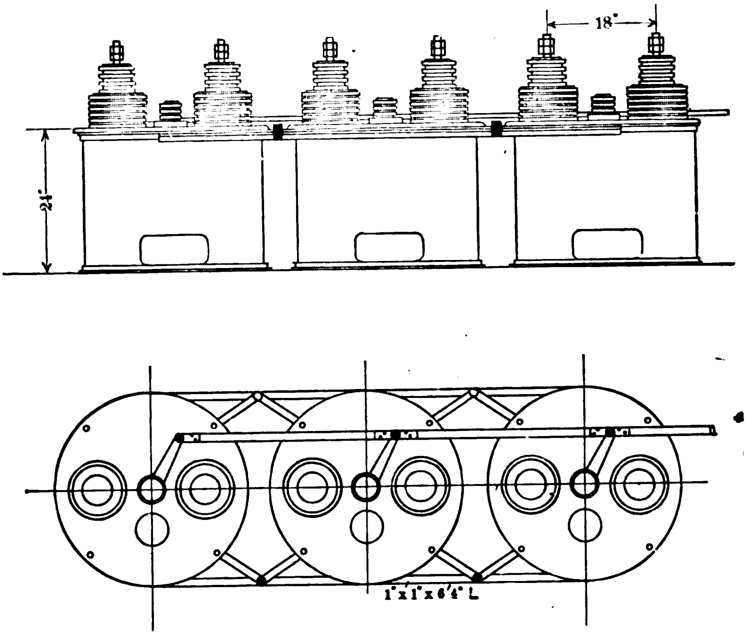

Fig. 7.—Three-pole grouping of oil-switches.

Structures of this kind are also sometimes used for river crossings where the cost of steel towers is prohibitive, or the time too short to install them. These are sometimes over 100 ft. high.

Referring to old lines which were constructed ten, or even five years ago, nearly all the lines were built with 40 poles to the mile, using 35-ft. poles. Now the tendency is to use longer spans on account of the lower cost and the reduced number of insulators or weak points in the line. Some of these old lines have later to be reconstructed for a higher voltage, and in order to obtain a reasonably good line and also to reduce the cost for insulators and future line maintenance it is advisable in reconstructing to reduce the number of poles. To do this, the supporting points of the wires must be raised higher above the ground. In order to accomplish the result of reinsulating and reconstructing several hundred miles of line (which would have kept all the insulator factories busy for two years furnishing insulators for the old type of construction), the pole-top extension shown in Fig. 3 was used. This has proved effective. By using this pole-top extension, every other pole is taken out, with a saving of $9.00 per pole for new insulators, with the additional salvage of the old poles, arms, pins, and insulators. Where sufficient height can be obtained by putting the arm below the top of the pole

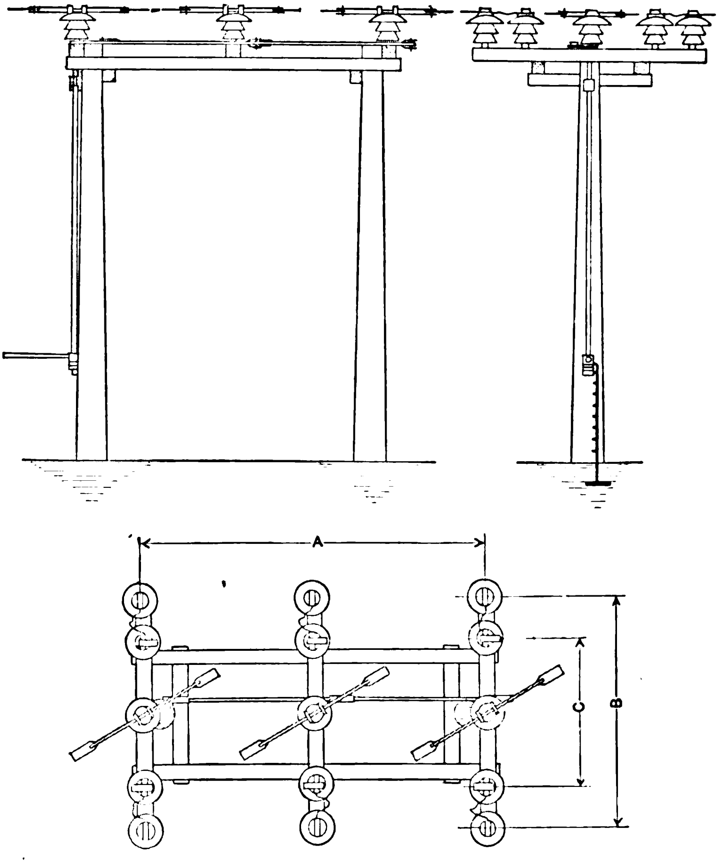

Fig. 8.—Outdoor two-break air-switch.

this construction may be simplified in the fastening of the arm and pipe to the pole.

Another important adjunct of the transmission line is the switches, oil and disconnecting. It will be found that the same arguments regarding economical line construction apply to switches. Five years ago no one was sure of a high-tension switch, and it would have been folly to install expensive switches of the first type that suggested itself, without giving them a thorough trial during several years under operating conditions. In selecting switches and structures for high-tension lines, it is well to bear in mind that the ultimate development has not yet been reached. In solving our switch problem this was kept in mind at all times.

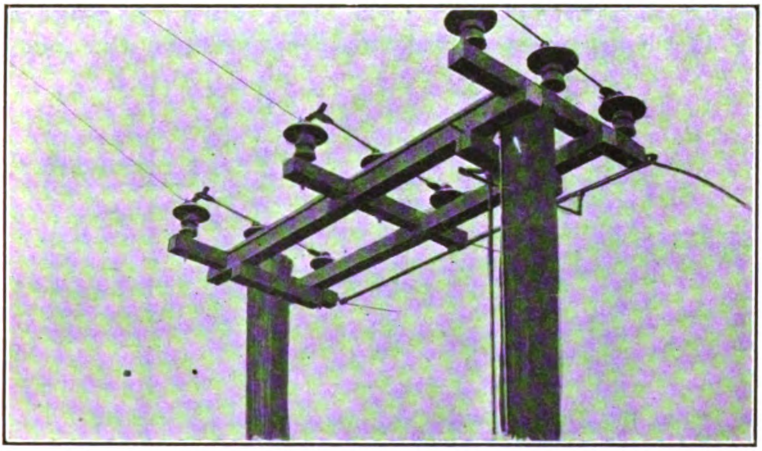

FIG. 9.—Outdoor switch.

The first high-tension oil-switches were made as inexpensive and as simple as possible, and were as shown in Fig. 4. These operated so satisfactorily that we became convinced of the success of the type and soon changed to a more substantial form, as shown in Fig. 5. They are generally installed for hand-operation.

Although we have more than 100 of these switches on our lines, and nearly 1000 miles at 60,000 volts all tied together, and over 50,000 kw. in generators operating on the lines at all times, the switches although cheaply constructed have given excellent results. All line switching is done on these high-tension switches, and the plants and lines are separated thereby in case of trouble. The stations are synchronized at sub-stations, which are 100 to 150 miles from any power station.

We have now adopted the type shown in Fig. 6, two-break switches for the ordinary station, and four-breaks in each tank for the heavy service. These switches are grouped in three-pole arrangement as shown in Fig. 7.

For small sub-stations and for line-sectionalizing switches and for disconnecting from bus-bars, switches of the type shown in Figs. 8 to 11 are used. In handling the high-tension lines these switches are used as much as the oil-switches.

Fig. 12 shows the lines and the main-line switching arrangements of the California Gas and Electric Corporation. *A O* represents an oil-switch and *An X* an air-break switch. A glance at Fig. 13 will show that our high-tension lines are also practically distributing lines, as loads are taken off at a great many points. We have more than 100 sub-stations on our lines. Such a system is, of course, much more difficult to operate than a straight away line with a power station at one end and a load at the other.

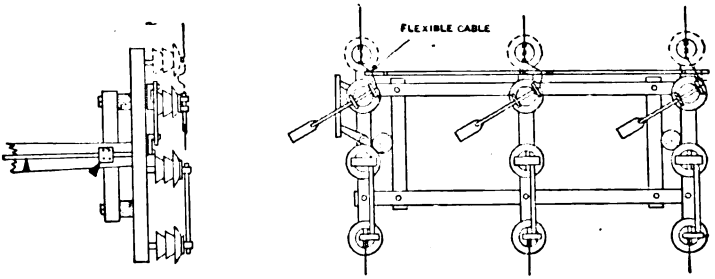

FIG. 10.—Outdoor switch and fuse for small sub-stations.

On the hydraulic construction and also on the power-house and sub-station installation and construction, the engineer is required to devise something that will pay the largest net income in a given number of years. Sometimes he is called upon to make installations on the assumption that the plant is to be abandoned in a few years. Of course, the engineer will be criticized if he puts in a plant to meet present or apparent future needs and, due to some change in the industry or development of the country, the plant must be remodeled later. But it is the business of the engineer to solve his problems as he sees them.

I have given these examples of line and switch construction to show that *the best solution of a problem may be one which accomplishes the purpose satisfactorily with the least amount of money*, on account of the changes in design which become apparent as our experience is broadened and as the industry develops. That there will be further advances is certain, but, as far as high-tension work is concerned, little of the present apparatus—transformers, insulators, switches—need be thrown away; for should the line voltage be forced up, the present apparatus may be used on the lower voltage lines. And too, the high-tension transformer is so flexible in its operating voltage connections that use can always be found for it. It is very probable that in time higher voltage trunk lines will be built which will feed into the present lower pressure (60,000 volts) lines at various points, using the present 60,000-volt lines for the primary distribution, stepping down to about 11,000 for the regular factory distribution. An example of work of this kind is shown by our system. A great many miles of comparatively low-tension lines—10,000 to 23,000— have been changed to higher voltage, but all the old line

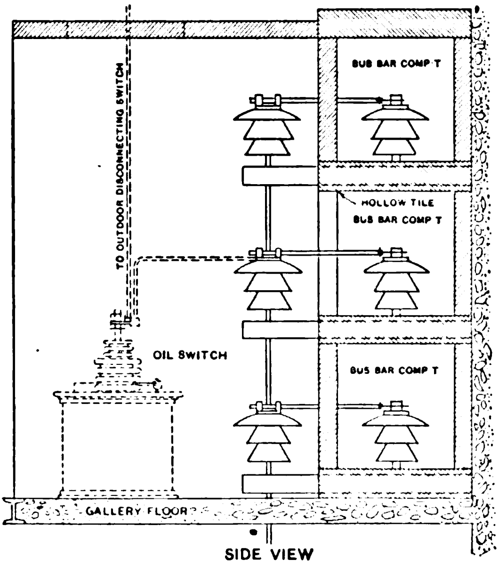

FIG. 11.—Oil-switch in compartment, showing disconnecting-switches.

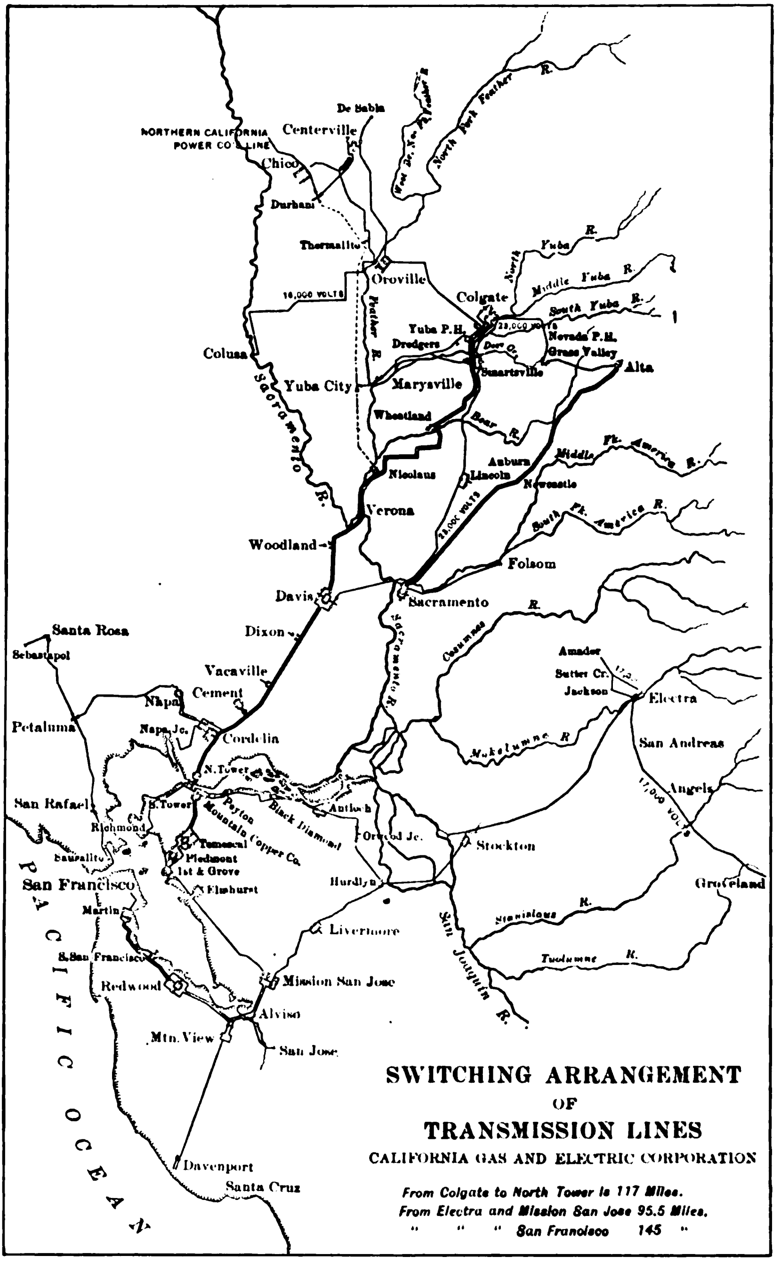

FIG.—All lines not otherwise marked are at 60,000 volts.

material, switches, insulators, transformers, etc., have been again utilized.

The saving in conducting capacity and the improvement in the service and the salvage have well paid for all the changes. No doubt a part of the future work of the electrical engineer will be to redesign and reconstruct the high-tension systems for the economies to be gained. The ease by which the change to the higher voltage may be made as necessity arises is encouraging alike to the transmission engineer and to the investor.

A paper to be presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 28, 1907

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THE VECTOR DIAGRAM OF THE COMPENSATED SINGLE-PHASE ALTERNATING-CURRENT MOTOR

BY W. I. SLICHTER

Although the compensated single-phase motor is simply a series circuit in physical connection, there are incidental reactions which have the effect of a combination of series and parallel circuits. These reactions have an effect on the efficiency and power-factor of sufficient importance to warrant a careful analysis of their character and cause.

As is well known, the motor circuits consist of an exciting field winding producing the field flux, an armature similar to that used in the usual direct-current motor, and a compensating winding wound in the faces of the poles and having its magnetic axis coincident with the axis of the armature reaction, but producing a magnetomotive force in the opposite direction. Thus in Fig. 1 is shown the diagram of connections of a four-pole compensated series motor. *F*, *FF* is the exciting winding with coils surrounding the pole pieces; *C*, *CC* is the compensating winding from pole to pole, and *A*, *AA* is the armature circuit. The current passes through these three in series, and the main reactions of one member on the others are very simple.

But the coil in the armature undergoing commutation encloses the main exciting or torque-producing flux, and as a result of the alternation of this flux at primary frequency, there is induced in the coil an electromotive force proportional to the primary frequency, and to the magnitude of the flux. The brushes complete the circuit of this coil, and a current flows therein proportional to this electromotive force, and inversely proportional to the impedance in the coil, brushes, and connections. This reproduces exactly the conditions existing in a transformer, the exciting winding F being the primary and the short-circuited coil BB being the secondary, as shown in Fig. 2.

In considering the reactions in the exciting winding, therefore, we must regard it as a complex circuit. The effect is the same as if the coil were shunted by an equivalent circuit having resistance and inductance as at Y in Fig. 2. This equivalent circuit represents the hysteretic current supplying the core-loss in the iron due to the alternation of the flux at primary frequency, and the current in the secondary coil BB.

Fig. 3 shows the relations of the various quantities in the exciting winding F. The resemblance to the transformer diagram will be noted. ϕ is the flux; the current which produces ϕ is $O\,F$, composed of $O\,B$, the wattless component and $O\,H$ the hysteretic component. $O\,A$ is the current in the secondary and this combines with $O\,F$ to form the primary or line current $O\,C = I_0$. $O\,E$, 90° ahead of the flux is the electromotive force consumed in the primary circuit. Neglecting the impedance drop, which is very small in this case, the voltage across the terminals of the exciting winding is therefore $O\,E$.

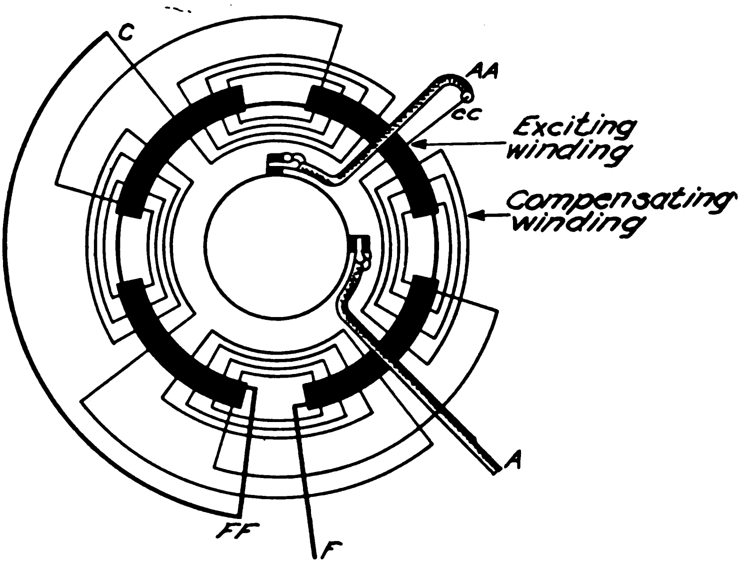

FIG. 1

In Fig. 4 we have this same diagram as a starting point for the general case. Thus with a main current I_0, represented by $O\,A$, we have $I_H = A\,B$ for the energy current in the equivalent shunt circuit, and $I_M = O\,B$ the wattless component in both the primary and shunt circuits, but consisting principally of the primary magnetizing current.

The flux ϕ is in phase with $O\,B$ and proportional to this primary component of $O\,B$ (not to the main current) and the permeance of the magnetic path.

The electromotive force induced in the exciting winding is $I\,X_M = O\,E$, and is 90° ahead of ϕ. The electromotive force consumed by the leakage reactance of all the windings will be 90° ahead of I_0 and proportional to I_0. This is represented by $I\,X_L = E\,F$. The electromotive force consumed by resistance is $I\,R = F\,G$, in phase with I_0.

The counter electromotive force due to the rotation of the armature conductors in the flux must be in phase with ϕ, thus $G\,H = e_2$ (drawn parallel to $O\,B$) represents this electromotive force in phase, while its magnitude is proportional to the angular speed of the armature.

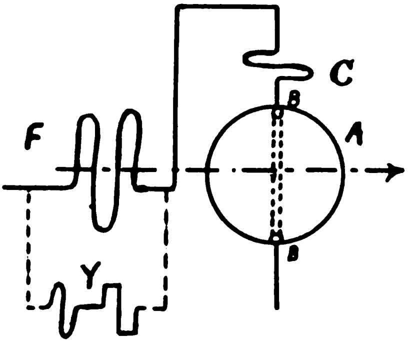

Fig. 2

The line potential E_0 is the resultant of all these components. Its magnitude determines the value of e_2, which in turn determines the speed. $O\,H$ represents the line potential, and the cosine of the angle $H\,O\,A = \gamma$ between E_0 and I_0 is the power-factor of the motor.

The product of $e_2\,I_0 \cos\alpha$ represents the output at the armature conductors. To obtain the true motor output, the armature core-loss, due to rotation, and the friction loss should be subtracted from this.

The calculation of power-factor and efficiency is made starting with the displacement angle α whose sine is $I_H \div I_0$. Assuming the phase of I_0 as a reference point, we have the following resolution of the terminal electromotive force E_0.

Wattless	Energy
$I\ X_M \cos\alpha$	$I\ X_M \sin\alpha$
$I\ X_L$	$I\ R$
$-e_2 \sin\alpha$	$e_2 \cos\alpha$

The exact analytical expression of the reactions is as follows:

Assume $e = I\ X_M$ the voltage across the exciting winding as reference vector or zero phase.

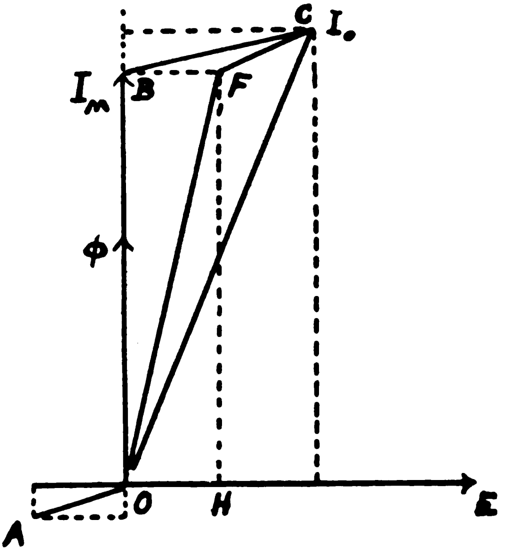

FIG. 3

Quantitatively $e = 4.44\ n\ N\ \phi\ 10^{-8}$

where: n = primary frequency.

N = number of exciting or field turns.

ϕ = flux per pole.

Admittance of exciting winding = $Y_1 = g_1 + j\ b_1$

Admittance of equivalent circuit = $Y_2 = g_2 + j\ b_2$

Admittance of combination $Y_x = Y_1 + Y_2 = g_x + j\ b_x$

Main line current = $I_0 = e\ (g_x + j\ b_x) = i_1 + j\ i_2$

Resistance of all circuits = r

Reactance (leakage) of all circuits = x

Impedance of motor (except exciting circuit) = $Z = r - j\ x$

Line voltage = E_0 is resolved into; electromotive force of rotation (e_2), electromotive force of excitation winding (e), and the impedance voltage $I_0 Z$.

e_2 is in phase with the flux ϕ and 90° from e; therefore, if e is the base of vectors, the electromotive force of rotation is expressed in phase position by $j\, e_2$.

Hence $E_0 = e + j\, e_2 + (I_0 Z)$

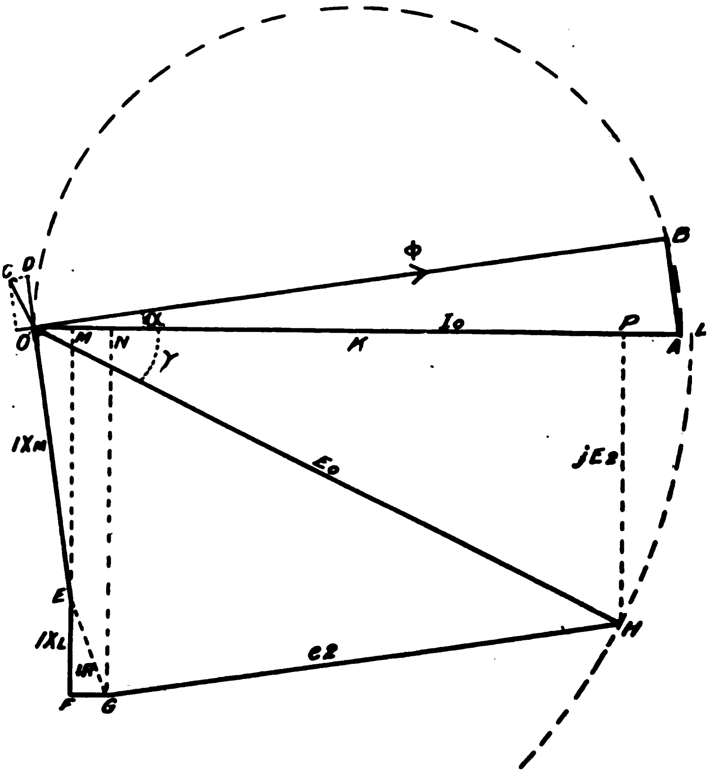

FIG. 4

Substituting:

$$= e + j\, e_2 + (i_1 + j\, i_2)\, (r - j\, x)$$

$$= e + i_1 r + i_2 x + j\, (e_2 + i_2\, r - i_1\, x)$$

Reducing to absolute terms:

$$E_0^2 = (e + i_1 r + i_2 x)^2 + (e_2 + i_2\, r - i_1\, x)^2$$

Solving for e_2:

$$e_2 = \sqrt{E_0^2 - (e + i_1 r + i_2 x)^2 - (i_2 r - i_1 x)}$$

The output at the armature conductors is the product of the counter electromotive force and the current in phase with it, $e_2\ i_2$.

Apparent input $= E_0\ I_0$

$$= [e + i_1 r + i_2 x + j\ (e_2 + i_2 r - i_1 x)]\ (i_1 + j\ i_2)$$

Power input is the real component of above.

$$= i_1\ (e + i_1 r + i_2 x)\ + i_2\ (e_2 + i_2 r - i_1\ x)$$

The peculiar features introduced by this equivalent shunt circuit are:

The counter electromotive force of rotation is not in phase with the main current, thus their product is not all energy.

The current in the armature I_0 is not in phase with the field flux and the torque is not truly proportional to the current, but is reduced by this displacement.

The more inductive the current in the short-circuited coil the less is this displacement, thus a resistance to limit the flow of current is not as valuable as some inductive effect.

The counter electromotive force e_2 being at an angle with the main current I_0, it is possible by increasing the speed and magnitude of e_2, or by increasing the angle α, to cause the point H to lie in $O\ L$ produced, thus making E_0 coincide with I_0, giving unity power-factor, or to cause e_2 to cross I_0, giving a leading current condition. These of course are extreme conditions resulting from a very high speed or from large losses in the equivalent shunt circuit.

The wattless component of the counter electromotive force ($-e_2 \sin \alpha$) has a marked effect on raising the power-factor, considerably more than the mere addition of the amount of energy which causes the phenomenon.

A paper to be presented at the Annual Convention Meeting of the Amercian Institute of Electrical Engineers, Niagara Falls, June 28, 1907

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INDUCTIVE DISTURBANCES IN TELEPHONE LINE.

BY LOUIS COHEN.

The inductive action of one telephone line on another, producing what is commonly known as cross-talk, presents an important problem to the telephone engineer. The induction is both electromagnetic and electrostatic. A variable current passing through any circuit is accompanied by a variable magnetic field, which will produce electric currents in neighboring circuits. In addition to this there exists also an electrostatic effect, a charge on one conductor will induce charges on all neighboring conductors, and any variation in the charge will produce an electric current. We thus have two distinct phenomena acting simultaneously, both causing trouble on telephone lines. It is to be noticed, however, that the two effects act in opposite directions. The establishment of a current in one circuit is accompanied by an induced current in any neighboring circuit in the opposite direction, while when the current in the inducing circuit is decreasing, the induced current will be in the same direction. In the case of electrostatic induction the conditions are reversed. When both forms of induction act together we obtain a resultant effect which depends on the various electrical constants of the lines and their relative importance. It would appear therefore quite evident that to obtain a knowledge of the effect due to induction, we must first be able to ascertain the relative importance of one form of induction as compared with the other, and to determine the factors which enter in fixing the magnitude of each. A thorough knowledge of these factors may be of considerable assistance in improving the conditions of telephone lines, or at least it may suggest some methods for overcoming induction effects which are a source of considerable annoyance to users of telephones.

In a paper presented before the American Institute of Electrical Engineers in 1891,* Mr. J. J. Carty discussed a series of experiments which he had conducted to determine the relative importance of the electrostatic as compared with the electromagnetic induction. His conclusions were that the electromagnetic effect is entirely negligible as compared with the electrostatic effect; in fact in his experiments he has not been able to detect any electromagnetic effect at all. In the discussion of his paper Mr. Carty made the following statement:

> "I go so far as to set forth that the effect of electromagnetic induction between parallel telephone wires may be neglected. That is, that when a man is talking on one wire and his speech is heard by induction on a parallel wire, that that speech finds its way between the two wires by virtue of electrostatic induction, and that electromagnetic induction is entirely negligible."

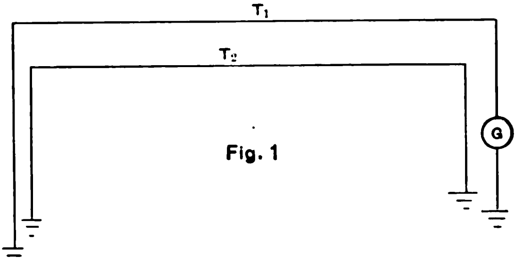

Fig. 1

This view expressed by Mr. Carty has generally been accepted by telephone engineers, and is usually given a very prominent place in all text books on telephony.

In what follows I shall discuss this question from a mathematical standpoint, and shall show that not only is the electromagnetic induction not a negligible quantity, but that in some cases the electromagnetic effect may be much larger than the electrostatic effect; and I shall further show that the results Mr. Carty obtained were correct, that under the conditions of Mr. Carty's experiments he could have obtained only an electrostatic effect. To infer, however, from his results, as Mr. Carty has done, that what is true for the case he experimented with—

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* J. J. Carty, TRANSACTIONS. of the A. I. E. E. 1891. Vol. 8, page 114.

a line three hundred feet long—is equally true for a line so many miles long is, as I will show, quite erroneous.

Suppose we have two lines T_1 and T_2 running parallel to each other and both are grounded at the two ends; T_1 may be a power circuit or telephone circuit, G is a source of an alternating electromotive force, and T_2 a telephone line. We wish to consider what is the nature of the induced currents in line T_2.

Let L_1, R_1, C_1, denote the self-inductance, resistance, and capacity per unit length of line T_1, and similar letters with suffix 2 denote the same constants of line T_2; M will denote the mutual electromagnetic inductance and C_{12} the mutual electrostatic inductance. Let also x and y denote the currents, V_1 and V_2 the potentials at any point on the lines T_1 and T_2.

The algebraic sum of the forces acting at any point on the two lines will be given by the following equations:

$$L_1 \frac{dx}{dt} + R_1 x + M \frac{dy}{dt} + \frac{dV_1}{ds} = 0$$

$$L_2 \frac{dy}{dt} + R_2 y + M \frac{dx}{dt} + \frac{dV_2}{ds} = 0 \qquad (1)$$

We also have the electrostatic relation,

$$C_1 V_1 + C_{12} V_2 = q_1$$

$$C_2 V_2 + C_{12} V_1 = q_2 \qquad (2)$$

By the aid of the equations of continuity

$$\frac{dq_1}{dt} = -\frac{dx}{ds}$$

$$\frac{dq_2}{dt} = -\frac{dy}{ds}$$

we may write equations (2) after differentiating with respect to t in the following form:

$$C_1 \frac{dV_1}{dt} + C_{12} \frac{dV_2}{dt} = -\frac{dx}{ds}$$

$$C_2 \frac{dV_2}{dt} + C_{12} \frac{dV_1}{dt} = -\frac{dy}{ds} \qquad (3)$$

Differentiating equations (1) with respect to s we get:

$$\begin{aligned} L_1 \frac{d^2 x}{d t d s} + R_1 \frac{d x}{d s} + M \frac{d^2 y}{d t d s} + \frac{d^2 V_1}{d s^2} &= 0 \\ L_2 \frac{d^2 y}{d t d s} + R_2 \frac{d y}{d s} + M \frac{d^2 x}{d t d s} + \frac{d^2 V_2}{d s^2} &= 0 \end{aligned} \tag{4}$$

If we differentiate equations (3) with respect to t, and introduce the values of $\frac{d^2 x}{d s d t}$, $\frac{d^2 y}{d s d t}$ thus obtained into equations (4) and also the values of $\frac{d x}{d s}$ and $\frac{d y}{d s}$ from equations (3) we shall obtain the following equations:

$$\begin{aligned} & L_1 C_1 \frac{d^2 V_1}{d t^2} + L_1 C_{12} \frac{d^2 V_2}{d t^2} + R_1 C_1 \frac{d V_1}{d t} + R_1 C_{12} \frac{d V_2}{d t} \\ & + M C_2 \frac{d^2 V_2}{d t^2} + M C_{12} \frac{d^2 V_1}{d t^2} = \frac{d^2 V_1}{d s^2} \\ & L_2 C_2 \frac{d^2 V_2}{d t^2} + L_2 C_{12} \frac{d^2 V_1}{d t^2} + R_2 C_2 \frac{d V_2}{d t} + R_2 C_{12} \frac{d V_1}{d t} \\ & + M C_1 \frac{d^2 V_1}{d t} + M C_{12} \frac{d^2 V_2}{d t^2} = \frac{d^2 V_2}{d s^2} \end{aligned} \tag{5}$$

Assuming that the impressed electromotive force be simple harmonic, that is the real part of $E e^{ipt}$ say, then the potentials at any point along the lines will be simple harmonic, and therefore we may put:

$$\frac{d^2 V_1}{d t^2} = - p^2 V_1, \quad \frac{d V_1}{d t} = i p V_1$$

$$\frac{d^2 V_2}{d t^2} = - p^2 V_2, \quad \frac{d V_2}{d t} = i p V_2$$

Introducing these values in equation (5) and rearranging we get:

$$\begin{aligned} \frac{d^2 V_1}{d s^2} &= a_1 V_1 + b_1 V_2 \\ \frac{d^2 V_2}{d s^2} &= a_2 V_2 + b_2 V_1 \end{aligned} \qquad (6)$$

Where,

$$\begin{aligned} a_1 &= -p^2 L_1 C_1 + i p R_1 C_1 - M C_{12} p^2 \\ b_1 &= -p^2 L_1 C_{12} + i p R_1 C_{12} - M C_2 p^2 \\ a_2 &= -p^2 L_2 C_2 + i p R_2 C_2 - M C_{12} p^2 \\ b_2 &= -p^2 L_2 C_{12} + i p R_2 C_{12} - M C_1 p^2 \end{aligned} \qquad (7)$$

Each of the equations (6) contains two dependent variables which make it rather difficult to solve. We can, however, transform equations (6) into equations containing only one dependent variable by the following device:*

Put

$$\begin{aligned} V_1 &= W_1 + W_2 \\ V_2 &= f_1 W_1 + f_2 W_2 \end{aligned}$$

where f_1 and f_2 are arbitrary constants.

Equations (6) will transform into the following:

$$\frac{d^2 W_1}{d s^2} + \frac{d^2 W_2}{d s^2} = (a_1 + b_1 f_1) W_1 + (a_1 + b_1 f_2) W_2$$

$$f_1 \frac{d^2 W_1}{d s^2} + f_2 \frac{d^2 W_2}{d s^2} = (a_2 f_1 + b_1) W_1 + (a_2 f_2 + b_2) W_2$$

Eliminating first W_1 and then W_2 we get the following equations:

$$\begin{aligned} &(a_2 f_2 + b_2 - a_1 f_1 - b_1 f_1 f_2) \frac{d^2 W_1}{d s^2} + (a_2 f_2 + b_2 - a_1 f_2 - b_1 f_2^2) \frac{d^2 W_2}{d s^2} \\ &= (a_1 a_2 - b_1 b_2)(f_2 - f_1) W_1 \\ &(a_2 f_1 + C_2 - a_1 f_1 - C_1 f_1^2) \frac{d^2 W_1}{d s^2} + (a_2 f_1 + C_1 - a_1 f_2 - C_1 f_1 f_2) \frac{d^2 W_2}{d s^2} \\ &= (a_1 a_2 - C_1 C_2)(f_1 - f_2) W_2 \end{aligned} \qquad (8)$$

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*See O. Heaviside coll. papers, vol. 1, p. 126.

now determine f_2 and f_1 from the equations

$$a_2 f_2 + b_2 - a_1 f_2 - b_1 f_2^2 = 0$$

$$a_2 f_1 + b_2 - a_1 f_1 - b_1 f_1^2 = 0$$

that is,

$$\left.\begin{aligned} f_2 &= \frac{a_2 - a_1 \pm \sqrt{(a_1 - a_2)^2 + 4\, b_1\, b_2}}{2\, b_1} \\ f_1 &= \frac{a_2 - a_1 \pm \sqrt{(a_1 - a_2)^2 + 4\, b_1\, b_2}}{2\, b_1} \end{aligned}\right\} \qquad (9)$$

Equations (8) will reduce to the following:

$$\left.\begin{aligned} \frac{d^2 W_1}{d s^2} &= \overline{K^2}\, W_1 \\ \frac{d^2 W_2}{d s^2} &= P^2\, W_2 \end{aligned}\right\} \qquad (10)$$

where,

$$\left.\begin{aligned} \overline{K^2} &= \frac{(a_1 a_2 - b_1 b_2)\,(f_2 - f_1)}{a_2 f_2 + b_2 - a_1 f_1 - b_1 f_1 f_2} \\ P^2 &= \frac{(a_1 a_2 - b_1 b_2)\,(f_1 - f_2)}{a_2 f_1 + b_2 - a_1 f_2 - b_1 f_1 f_2} \end{aligned}\right\} \qquad (11)$$

The complete solutions of (10) will be the following:

$$\left.\begin{aligned} W_1 &= A \cos \mu\,(l - s) + B \sin \mu\,(l - s) \\ W_2 &= D \cos \mu_1\,(l - s) + F \sin \mu_1\,(l - s) \end{aligned}\right\} \qquad (12)$$

The constants are to be determined from the following boundary conditions:

When

$$s = 0, \qquad V_1 = E\, e^{ipt} \qquad V_2 = 0$$

$$s = l, \qquad V_1 = 0, \qquad V_2 = 0$$

Now,

$$W_1 = \frac{f_1 V_1 - V_2}{f_1 - f_2}, \qquad W_2 = \frac{f_2 V_1 - V_2}{f_2 - f_1}$$

Hence, when $s = 0$

$$W_1 = A \cos \mu l + B \sin \mu l = \frac{f_1 \, E e^{ipt}}{f_1 - f_2}$$

$$W_2 = D \cos \mu_1 l + F \sin \mu_1 l = \frac{f_2 \, E e^{ipt}}{f_2 - f_1}$$

When $s = l$,

$$W_1 = A = 0$$
$$W_2 = D = 0$$

and therefore,

$$B = \frac{f_1 \, E e^{ipt}}{(f_1 - f_2) \sin \mu l}$$

$$F = \frac{f_2 \, E e^{ipt}}{(f_2 - f_1) \sin \mu_1 l}$$

Introducing the values of the constants thus obtained into equation (12) we shall obtain the following values for V_1 and V_2:

$$V_1 = W_1 + W_2 = \left(f_1 \frac{\sin \mu (l - s)}{\sin \mu l} - f_2 \frac{\sin \mu_1 (l - s)}{\sin \mu_1 l} \right) \frac{E e^{ipt}}{f_1 - f_2}$$

(13)

$$V_2 = f_1 W_1 + f_2 W_2 = \left(f_1^2 \frac{\sin \mu (l - s)}{\sin \mu l} - f_2^2 \frac{\sin \mu_1 (l - s)}{\sin \mu_1 l} \right) \frac{E e^{ipt}}{f_1 - f_2}$$

The values of μ and μ_1 may be obtained by inspection of equation (10) which gives

$$-\mu^2 = \overline{K^2} = \frac{(a_1 a_2 - b_1 b_2)(f_2 - f_1)}{a_2 f_2 + b_2 - a_1 f_1 - b_1 f_1 f_2}$$

(14)

$$-\mu_1^2 = P^2 = \frac{(a_1 a_2 - b_1 b_2)(f_1 - f_2)}{a_2 f_1 + b_1 - a_1 f_2 - b_1 f_1 f_2}$$

The value of the currents in the two lines can be easily obtained from equation (13) by the aid of equation (3). Thus:

$$-x = \Bigg[C_1 i p \left(\frac{f_1 \cos \mu (l-s)}{\mu \sin \mu l} - f_2 \frac{f_2 \cos \mu_1 (l-s)}{\mu_1 \sin \mu_1 l}\right)$$

$$+ i C_{12} p \left(\frac{f_1^2 \cos \mu (l-s)}{\mu \sin \mu l} - \frac{f_2^2 \cos \mu_1 (l-s)}{\mu_1 \sin \mu_1 l}\right)\Bigg] \frac{E e^{ipt}}{f_1 - f_2}$$

$$(15)$$

$$-y = \Bigg[C_2 i p \left(\frac{f_1^2 \cos \mu (l-s)}{\mu \sin \mu l} - \frac{f_2^2 \cos \mu_1 (l-s)}{\mu_1 \sin \mu_1 l}\right)$$

$$+ i C_{12} p \left(\frac{f_1 \cos \mu (l-s)}{\mu \sin \mu l} - \frac{f_2 \cos \mu_1 (l-s)}{\mu_1 \sin \mu_1 l}\right)\Bigg] \frac{E e^{ipt}}{f_1 - f_2}$$

Rearranging we obtain:

$$-x = \Bigg((C_1 f_1 + C_{12} f_1^2) \frac{\cos \mu (l-s)}{\mu \sin \mu l}$$

$$- (C_1 f_2 + C_{12} f_2^2) \frac{\cos \mu_1 (l-s)}{\mu_1 \sin \mu_1 l}\Bigg) \frac{i p E e^{ipt}}{f_1 - f_2}$$

$$(16)$$

$$-y = \Bigg((C_2 f_1^2 + C_{12} f_1) \frac{\cos \mu (l-s)}{\mu \sin \mu l}$$

$$- (C_2 f_2^2 + C_{12} f_2) \frac{\cos \mu_1 (l-s)}{\mu_1 \sin \mu_1 l}\Bigg) \frac{i p E e^{ipt}}{f_1 - f_2}$$

The second equation of (16) gives us the final expression for the currents in any wire due to electromagnetic and electrostatic induction of a parallel wire. The inducing line may be part of a power circuit, lighting circuit, or a similar telephone line. In deducing equations (16) we have taken account of the difference in dimensions, or electrical constants, of the two lines which react upon each other, which will of course be the case if we wish to calculate the currents induced in a telephone line by a power circuit running parallel to it.

According to some recent reports, the introduction of the single-phase electric railway plays havoc with service on telephone and telegraph lines which parallel the railways. This will in all probability be a very serious problem, and a careful consideration of equation (16) will give us a better insight into the nature of the problem and the magnitude of the disturbance. It may also possibly suggest some means for eliminating these disturbances or at least reducing them to a minimum. I hope to consider this phase of the problem in another paper, but for the present I shall limit my discussion to the case of two parallel telephone lines.

If it is the influence of two telephone lines on each other that we wish to investigate, then equations (16) will be somewhat simplified; for in that case we find by examining equations (6) that

$$a_1 = a_2 \qquad\qquad b_1 = b_2$$

equations (9) will therefore reduce to

$$f_1 = -f_2 = 1$$

Hence equations (16) will become,

$$-x = \tfrac{1}{2}\left((C+C_{12})\frac{\cos\mu\,(l-s)}{\mu\sin\mu\,l} + (C-C_{12})\frac{\cos\mu_1\,(l-s)}{\mu_1\sin\mu_1\,l}\right) i\,p\,E\,e^{ipt}$$

$$-y = \tfrac{1}{2}\left((C+C_{12})\frac{\cos\mu\,(l-s)}{\mu\sin\mu\,l} - (C-C_{12})\frac{\cos\mu_1\,(l-s)}{\mu_1\sin\mu_1\,l}\right) i\,p\,E\,e^{ipt} \qquad (17)$$

The values of μ and μ_1 are given by equations (14) which in the case of two parallel wires reduce to the following:

$$\begin{aligned} -\mu^2 &= a+b = -p^2(L+M)(C+C_{12}) + i\,p\,R\,(C+C_{12}) \\ -\mu_1^2 &= a-b = -p^2(L-M)(C-C_{12}) + i\,p\,R\,(C-C_{12}) \end{aligned} \qquad (17)$$

μ and μ_1 are of course complex quantities, putting

$$\mu = \alpha + i\,\beta \qquad\qquad \mu_1 = \alpha_1 + i\,\beta_1$$

and solving for α, β, α_1 and β_1 we get

$$\begin{aligned} \alpha &= \sqrt{\tfrac{1}{2}\,p\,(C+C_{12})\left[\sqrt{p^2(L+M)^2+R^2}+p\,(L+M)\right]} \\ \beta &= \sqrt{\tfrac{1}{2}\,p\,(C+C_{12})\left[\sqrt{p^2(L+M)^2+R^2}-p\,(L+M)\right]} \\ \alpha_1 &= \sqrt{\tfrac{1}{2}\,p\,(C-C_{12})\left[\sqrt{p^2(L-M)^2+R^2}+p\,(L-M)\right]} \\ \beta &= \sqrt{\tfrac{1}{2}\,p\,(C-C_{12})\left[\sqrt{p^2(L-M)^2+R^2}-p\,(L-M)\right]} \end{aligned} \qquad (18)$$

It remains now to separate the values of x and y into the real and imaginary parts, for the actual currents in the lines will be the real parts of the values of x and y as given by equation (17). Now

$$\frac{i\,p\,E\,e^{ipt}}{\mu \sin \mu\, l} = \frac{i\,p\,E\,(\cos p\,t + i \sin p\,t)}{(\alpha + i\,\beta)\sin(\alpha + i\,\beta)\,l} =$$

$$\frac{2(\alpha - i\beta)\,(\sin \alpha l\,(e^{\beta l} + e^{-\beta l}) - i \cos \alpha l\,(e^{\beta l} - e^{-\beta l}))\,E\,i\,p\,(\cos p t + i \sin p t)}{(\alpha^2 + \beta^2)\,[\sin^2 \alpha\, l\,(e^{2\beta l} + 2 + e^{-2\beta l}) + \cos^2 \alpha\, l\,(e^{2\beta l} - 2 + e^{-2\beta l}]}$$

the real part of which is

$$\frac{2\,E\,p\Big[\Big\{\beta \cos \alpha\, l\,(e^{\beta l} - e^{-\beta l}) - \alpha \sin \alpha\, l\,(e^{\beta l} + e^{-\beta l})\Big\}\sin p\,t + \Big\{\beta \sin \alpha\, l\,(e^{\beta l} + e^{-\beta l}) + \alpha \cos \alpha\, l\,(e^{\beta l} - e^{-\beta l})\Big\}\cos p\,t\Big]}{(\alpha^2 + \beta^2)\,(e^{2\beta l} + e^{-2\beta l} - 2\cos 2\,\alpha\, l)}$$

$$= \frac{2\,E\,p \sin (p^t\,\phi)}{\sqrt{(\alpha^2 + \beta^2)\,(2\cos h\,2\,\beta\, l - 2\cos 2\,\alpha\, l)}} \tag{19}$$

Where $\tan \phi =$

$$\frac{\beta \sin \alpha\, l\,(e^{\beta l} + e^{-\beta l}) + \alpha \cos \alpha\, l\,(e^{\beta l} - e^{-\beta l})}{\beta \cos \alpha\, l\,(e^{\beta l} - e^{-\beta l}) - \alpha \sin \alpha\, l\,(e^{\beta l} + e^{-\beta l})} \tag{20}$$

When $\beta\, l$ is a very small quantity, then approximately

$$\tan \phi = -\frac{\beta}{\alpha} \tag{21}$$

When $\beta\, l$ is very large, then the above equation will be approximately

$$\tan \phi = \frac{\beta \sin \alpha\, l + \alpha \cos \alpha\, l}{\beta \cos \alpha\, l - \alpha \sin \alpha\, l} \tag{22}$$

At the end of the line, say when $s = l$, the values of the currents will therefore be given by the following equations:

$$\begin{aligned} -x_l = E\,p\Bigg\{&\frac{(C_1 + C_{12})\sin(p\,t + \phi)}{\sqrt{(\alpha^2 + \beta^2)\,(2\cos h\,2\,\beta\, l - 2\cos 2\,\alpha\, l)}} \\ &+ \frac{(C_1 - C_{12})\sin(p\,t + \phi_1)}{\sqrt{(\alpha_1^2 + \beta_1^2)\,(2\cos h\,2\,\beta_1\, l - 2\cos 2\,\alpha_1\, l)}}\Bigg\} \\ -y_l = E\,p\Bigg\{&\frac{(C_1 + C_{12})\sin(p\,t + \phi)}{\sqrt{(\alpha^2 + \beta^2)\,(2\cos h\,2\,\beta\, l - 2\cos 2\,\alpha\, l)}} \\ &- \frac{(C_1 - C_{12})\sin(p\,t + \phi_1)}{\sqrt{(\alpha_1^2 + \beta_1^2)\,(2\cos h\,2\,\beta_1\, l - 2\cos 2\,\alpha_1\, l)}}\Bigg\} \end{aligned} \tag{23}$$

The second equation of (23) represents the current at one end of the line T_2 due to the electromagnetic and electrostatic induction. We may put equation (23) in a more convenient form, thus:

$$y_l = E\,p\,\sqrt{A^2 + B^2 - 2\,A\,B \cos(\phi - {}_1\phi)}\,\sin(p\,t + \phi) \qquad (24)$$

Where

$$A = \frac{C - C_{12}}{\sqrt{(\alpha_1{}^2 + \beta_1{}^2)\,(2 \cos h\, 2\,\beta_1\,l - 2 \cos 2\,\alpha_1\,l)}}$$

$$B = \frac{C + C_{12}}{\sqrt{(\alpha^2 + \beta^2)\,(2 \cos h\, 2\,\beta\,l - 2 \cos 2\,\alpha\,l)}} \qquad (25)$$

$$\tan\phi = \frac{A \cos\phi_1 - B \cos\phi}{A \sin\phi_1 - B \sin\phi}$$

The maximum value of the current will evidently be,

$$E\,p\,\sqrt{A^2 + B^2 - 2\,A\,B \cos(\phi - \phi_1)}.$$

Now to find the ratio of the electrostatic to the electromagnetic induction, we calculate the value of y_l as given by equation (24) first on the supposition that $M = 0$; that is, that the whole effect is purely electrostatic, and then calculate the value of y_l on putting $C_{12} = 0$; that is, assuming that the effect is purely electromagnetic. We can thus obtain an estimate of the relative importance of the two forms of induction in causing disturbances in parallel lines. The values of the various electrical coefficients which enter into the calculations were determined from formulas given by Mr. Heaviside* in his collected papers, which are as follows:

$$L = \tfrac{1}{2} + 2 \log \frac{2\,h}{r}$$

$$M = \log \frac{d^2 + (h_1 + h_2)^2}{d^2 + (h_1 - h_2)^2}$$

$$C_1 = \frac{2 \log \frac{2\,h}{r}}{\left(2 \log \frac{2\,h}{r}\right)^2 - \left(\log \frac{d^2 + 4\,h^2}{d^2}\right)^2}$$

$$- C_{12} = \frac{\log \frac{d^2 + 4\,h^2}{d^2}}{\left(2 \log \frac{2\,h}{r}\right)^2 - \left(\log \frac{d^2 + 4\,h^2}{d^2}\right)^2} \qquad (26)$$

***O. Heaviside collected papers, Vol. 1, pp. 44 and 101.**

These formulas apply to the case of parallel suspended wires where h is the height above the ground, d is the distance between the wires, and r is the radius of the wire.

Let us now consider an example; suppose the two wires are 1.25 cm. apart, and at about 1000 cm. above the ground let the radius of each wire be 0.1 cm., then we find

L = 0.00203 henry per kilometre.
M = 0.00147 " " "
C = 0.0118 mf. " "
$-C_{12}$ = 0.0088 mf. " "
R = 3 ohms per kilometre approximately.

Using these values for the constants of the lines, I have calculated the maximum of the current y_l, as given by equation (24),

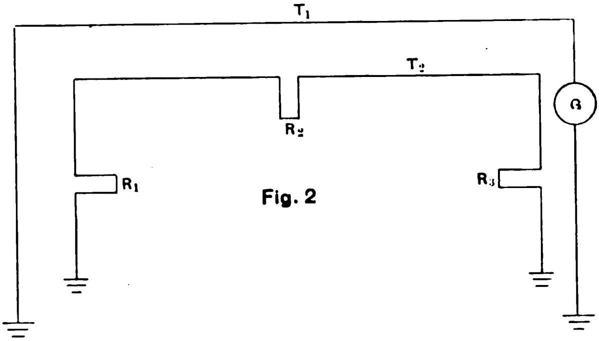

Fig. 2

first assuming that we have only electrostatic induction; that is, $M = 0$, and second assuming that we have only electromagnetic induction; that is, $C_{12} = 0$. The ratios of the two forms of induction for various lengths of lines given below:

l	$\frac{e.\ s.}{e.\ m.}$
0.1 km.	0.02
100 km.	0.44
1000 km.	1.6

From this short table it will be seen that for the particular case under consideration, the electromagnetic induction is far larger than the electrostatic; but as the length increases the electrostatic is gaining more rapidly than the electromagnetic, and thus at 1000 km., the electrostatic has overpowered the electromagnetic. In obtaining the above results we have assumed that our line does not have any telephone receiver in it, which is of course not the important case. In the case of a long line, however, say 100 km. or more, where the inductance of the line is large, compared with the inductance of the receiver, the introduction of a receiver will not modify the result to any great extent, but in the case of a short line, the introduction of one or more receivers may affect the results to a very great extent. Let us consider for example one of Mr. Carty's experiments.

There are two lines of about 0.1 km. long stretched side by side at a distance of about 1 cm. and there are three telephone receivers in the second line, the complete solution of this problem is not of course so simple, yet as an approximation we may consider the introduction of the telephone receivers in such a short line as a distributed inductance and resistance. If the inductance of each receiver is 0.05 henry and its resistance is 50 ohms, then for such a short line, the inductance per unit length will be $L = 1.5$ henry and $R = 1500$ ohms. Assuming these to be the constants of our line we find, on calculating as in the previous cases, that the current due to electromagnetic induction is practically zero, and it is only the current due to electrostatic induction that has any appreciable value, and this is what Mr. Carty obtained experimentally. To infer from this that electromagnetic induction is negligible in all cases is however, certainly incorrect. In the case of a long line, say 500 km., the induction and resistance of the telephone receivers will not modify to any great extent the constants of the line, and in that case the electromagnetic induction is just as important as the electrostatic induction. Which is the more important depends a great deal on the length of the lines, their height above the ground, and their distance apart. By varying any one of the above factors we shall vary the ratio of the electromagnetic to the electrostatic induction.

A report to be presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 27, 1907.

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(*Subject to final revision for the Transactions.*)

PROPOSED CODE OF ETHICS.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS COMMITTEE ON CODE OF ETHICS.

AMPERE, N. J., May 17, 1907.

To the President and Board of Directors of the American Institute of Electrical Engineers.

Gentlemen: Your committee, appointed at the annual convention at Milwaukee in June, 1906, to consider the advisability of preparing a code of engineering ethics, and, if thought best, to prepare such a code, has to report as follows:

While we do not consider it practicable at this time to formulate a code of ethics covering explicitly all the conditions which the electrical engineer may meet in his work, we do consider it both practicable and desirable to record some of the general principles of professional conduct that should be a guide for the electrical engineer, leaving it to him to make specific application to the cases which he may meet. We therefore submit and recommend the following, to be printed and distributed to the membership, with a view to its discussion and adoption at the approaching Annual Convention in June, 1907.

Respectfully submitted,

CHARLES P. STEINMETZ,
HAROLD W. BUCK,
SCHUYLER SKAATS WHEELER.
Chairman.

PRINCIPLES OF PROFESSIONAL CONDUCT FOR THE GUIDANCE OF THE ELECTRICAL ENGINEER.

A. General Principles.

B. Relations of the electrical engineer to his employer, customer, or client.

C. Relations of the electrical engineer to the ownership of the records of his work.

D. Relations of the electrical engineer to the public.

E. Relations of the electrical engineer to the engineering fraternity.

F. Relations of the electrical engineer to the standards of his profession.

A. General Principles.

1. In both his professional and his business relations the electrical engineer should follow strictly the same ethical principles that are recognized in the social relations of every-day life. He should consider himself personally responsible for the character of the enterprises and the persons with which he is associated professionally.

2. Before entering into professional relations, it is therefore the duty of the electrical engineer to satisfy himself that the enterprises with which he connects himself are of a legitimate character. If, after becoming associated he finds them to be of a questionable nature he should sever his connection as soon as possible. It should not be considered an excuse that his connection extends only to legitimate engineering work.

3. An electrical engineer permitting the use of his name in any enterprise or exploitation becomes morally responsible for the character of the latter. He should therefore not allow the use of his name in connection with anything upon which he is not qualified by training and experience to exercise competent judgment.

4. The electrical engineer should take care that credit for engineering work is attributed to those who, as far as his knowledge of the matter goes, are the real authors of such work.

5. The electrical engineer should incline toward and not away from standards of all kinds, since standardization is peculiarly essential to the general progress of the profession. This applies to construction, measurement and expression, or nomenclature as well as to conduct, or ethics. Even the tendency to give individuality by providing special construction may sometimes be avoided with advantage.

B. RELATIONS OF THE ELECTRICAL ENGINEER TO HIS EMPLOYER, CUSTOMER, OR CLIENT.

7. The electrical engineer should consider the protection of his client's interests as his first obligation, and therefore should avoid every act that would be contrary to this duty; if any other consideration such as professional obligations or restrictions interfere with his so acting, in accordance with the expectation of his client, he should inform him of the situation.

8. He can honorably accept compensation, financially or otherwise, from one side or party only, interested in the same matter. The electrical engineer, whether consulting, designing, or operating, may therefore not accept commissions, either directly or indirectly, from other parties dealing with his principals.

9. Electrical engineers in a position to decide on the use of inventions, apparatus, etc., should not be financially interested in their use, as by receiving a royalty, etc., unless the matter is clearly understood by the client.

10. Electrical engineers should not accept employment while financially interested in a rival concern except upon the express permission of both parties. An electrical engineer may be employed by more than one party, as in the case of a consulting engineer, when the interests of the parties do not conflict and it is understood, as is usual in such cases, that he is not expected to devote his entire time to the work of one party

but is free to enter into other engagements. A consulting engineer permanently retained by a party should notify other prospective employers of this affiliation before entering into relations with them. A consulting engineer when not exclusively retained by one side may advise rival concerns, with the full knowledge of all of them and upon taking care that the interests of the parties do not conflict in the particular matter handled.

11. Operating engineers should consider themselves responsible for defects in apparatus or dangerous conditions of operation, should bring the same to the attention of their employers and urge remedial action. If the causes of the danger are not removed they should withdraw.

12. An electrical engineer should in general be considered directly responsible to his employer or client for the successful fulfilment of the work upon which he has been engaged and for its satisfactory performance as a whole. It should therefore be clearly understood at the outset just what the extent or the limitations of responsibility of the engineer are to be. Whether he has been employed merely as designer or whether he is retained to design and to superintend construction; whether to design only the chief features, or to pass as well upon all details of the apparatus that is to be installed. Attention should be directed to the fact that defects in the manufacture of material or apparatus is a matter distinct from the matters of design or installation. An engineer should not be held responsible for the unsatisfactory performance of a plant resulting from defective apparatus furnished, unless he has undertaken to include this subject.

C. RELATIONS OF THE ELECTRICAL ENGINEER TO THE OWNERSHIP OF THE RECORDS OF HIS WORK:

15. The following general principles should be recognized:

If in executing his work, the electrical engineer uses data or information which are not common and public property, but which he receives, directly or indirectly from his employer, or if the problem solved by the engineer is met in the pursuit of his work for his employer, and is not of such character that his attention would have been directed to it regardless of his relations to his employer, the products of his work, in the form of inventions, plans, designs, etc., are not his private property, but the property of his employer, though the engineer may be entitled to special remuneration for such inventions, etc.

16. If in the execution of the work the engineer uses only his own knowledge or data or information which are public property by prior publication, etc., and receives no engineering data from his employer or customer, except performance specifications, the results of the work, such as inventions, plans, designs, etc. are the private property of the engineer, and his employer or customer is entitled to their use only in the specified case.

17. All the work done by the engineer in the form of inventions, plans, designs, etc., which are outside of the field of engineering for which his employer has retained him, are the engineer's private property.

18. When an engineer or manufacturer builds apparatus from engineering designs supplied to him by his customer, the designs remain the property of the customer and should not be duplicated for other cus-

tomers without express permission. When the engineer or manufacturer and his customer are jointly to work out designs and plans or develop inventions, a clear understanding should be arrived at before the beginning of the work regarding the proportionate rights of ownership in any inventions, designs, etc., that may result, since in such case both parties should be considered to have rights therein.

19. Any engineering data or information which an electrical engineer obtains, directly or indirectly, from his employer or customer, or which he creates as a result of such information, must be considered by the engineer as confidential; and while the engineer is justified in using such data or experience in his own practice as going towards his education, the publication thereof without express permission is improper, as is also its use in producing for other parties, work that is characteristic of the original customer or employer.

20. Designs, data, records and notes made during his engagement by an engineer employed under permanent engagement, and referring to his work, are his employer's property. The same matter in the case of a consulting electrical engineer are the property of the consulting engineer.

21. A customer, in buying apparatus, does not acquire any right in its design beyond the use in the apparatus purchased. A customer of a consulting engineer does no acquire any right to the plans made by the consulting engineer except for the specific case for which the apparatus was built or the plans made.

D. RELATIONS OF THE ELECTRICAL ENGINEER TO THE GENERAL PUBLIC.

22. The electrical engineer should endeavor to assist the public to a fair and correct general understanding ot engineering matters, spread the general knowledge of electrical engineering, and discourage wrong or exaggerated statements on engineering subjects published in the press or otherwise, especially if these statements are made for the purpose of, or may lead to inducing the public to participate in unworthy schemes.

23. Controversies on engineering questions, however, should never be carried on in the public press, but should be confined to the technical press and the engineering societies.

24. First publication of inventions or other engineering advances should not be made through the public press but rather through the technical press and the engineering societies.

25. The publications which an electrical engineer is justified in making through the public press should therefore be of a historical, educational, instructive or similar character and should not relate to controversies between engineers or on engineering questions, to new inventions, etc., nor contains technical criticisms of fellow engineers, and it should be considered unprofessional to give opinions without being fully informed on all the facts relating to the question, and on the purpose for which the opinion is asked, with a full statement of the conditions under which the opinion applies.

26. In giving expert testimony before judicial bodies, the electrical engineer should confine himself to brief and clear statements on engineering or historical facts. He should not give personal opinions without so expressly stating, and should avoid pleading on one side or the other.

E. RELATIONS OF THE ELECTRICAL ENGINEER TO THE ENGINEERING FRATERNITY.

30. The electrical engineer should take interest in and show due regard for the electrical engineering societies and the technical press.

31. He should assist his fellow engineers by exchange of general information, experience, instruction, etc.

32. He should not take a position left by another electrical engineer without satisfying himself that the former has left it voluntarily, or for proper reasons.

33. Where engineering work is in charge of an electrical engineer, no other electrical engineer should undertake the work except on request of or in coöperation with the electrical engineer who had charge of the work before, unless the latter's connection with it has already terminated.

34. An electrical engineer in responsible charge of work should not permit other engineers or non-technical persons to over-rule his electrical engineering decisions. If this is done and persisted in, he should as soon as is practicable withdraw.

35. In engineering work in charge of a board of engineers, the respective limitations of the authority of each should be decided at the outset, and each electrical engineer should give full and complete information on his part to the other engineers and insist on this being reciprocated.

F. RELATIONS OF THE ELECTRICAL ENGINEER TO THE STANDARDS OF HIS PROFESSION.

40. The title "electrician" should be applied to those having practical training sufficient to enable them to carry on intelligently certain classes of electrical work, such as the installation of electric lights, signaling systems, and the operation of small electric plants.

41. The title "electrical engineer" should be applied only to graduates from the electrical engineering schools of universities of recognized standing, and such men as possess an equivalent knowledge of electrical engineering.

42. The title "consulting electrical engineer" should be applied only to those electrical engineers who possess such knowledge and experience in electrical engineering as would qualify them to full membership in the American Institute of Electrical Engineers.

Signed.
CHARLES P. STEINMETZ,
HAROLD W. BUCK,
SCHUYLER SKAATS WHEELER.
Chairman.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF THE BOARD OF DIRECTORS FOR THE FISCAL YEAR ENDING APRIL 30, 1907.

The Board of Directors presents herewith for the information of the INSTITUTE a report of its work during the year, and of the various standing and special committees, also the financial standing of the organization.

The Annual Convention was held at Milwaukee, Wisconsin, May 28-31. The total registered attendance was 236. At this convention President Wheeler delivered his annual address upon the subject of Engineering Honor, and twenty professional papers were read and discussed, also the report of the Standardization Committee.

The Board of Directors has held nine monthly meetings during the year, and the Executive Committee one meeting.

In response to the invitation of the Institution of Electrical Engineers, a representative party from the American Institute of Electrical Engineers was organized to meet with European electrical engineers at London, June 24, 1906, and join with them as guests of the Institution in a circular tour through Great Britain. The Board of Directors was represented on this tour by President Wheeler, Past President Lieb, Manager C. O. Mailloux and the Secretary. There were in the party 23 Members and 12 guests from America, and 22 Members and 6 guests from foreign countries. An official banquet was given in honor of the visitors, at Hotel Cecil, June 25, at which about 500 guests were present. After devoting three days to various technical visits in London and vicinity, the party started June 28 on the circular tour, which included visits to Stratford, Rugby, Birmingham, Manchester, Liverpool, Glasgow, Edinburgh, Newcastle-on-Tyne, Leeds and Harrogate. This trip was made on a special train of dining coaches furnished by the London and Northwestern Railway. Every detail was successfully carried out, and the entire tour was not only instructive, but thorougly enjoyable in every respect.

Board of Examiners.—Ten meetings were held during the year, at which applications for election as Associates, enrolment as students, and transfer to the grade of Member have been reported to the Board of Directors as follows:

Recommended for election as Associates	944
Not recommended for election as Associates	4
Recommended for enrolment as students	459
Recommended for transfer to grade of Member	40
Not recommended for transfer to grade of Member	9
Reinstated to grade of Member	1
Held for further information	7
Total applications considered	1,464

Local Organization Committee.—This committee reports a present total of 33 local organizations included under the heads of Branches, University Branches and Student Meetings. The University of Illinois has been made a regular Branch by the Board, it having the requisite number of Members and Associates required by the By-laws. Student Meetings have also been authorized by the Board at the University of Maine and the Montana Agricultural College. A design for a student's pin has been authorized, and a supply ordered for sale. A conference with the Editing Committee led to an arrangement for the publication of meritorious original papers emanating from the Branches. There have been over two hundred Branch meetings held, with a total attendance of 16,500. At these meetings 137 original papers have been presented. Cornell shows an average attendance of 130, with a maximum of 225, Purdue an average of 100, with a maximum of 265, Wisconsin an average of 60, with a maximum of 175. All of the University Branches show that the enrolled Students are taking an active interest in the work. As soon as the revenue of the INSTITUTE will permit, it is the general belief that arrangements should be made for the systematic visitation of Branches by officers of the INSTITUTE and prominent engineers. There is a general call for some action of this kind which it is hoped would be productive in general good fellowship. The encouragement of the attendance of delegates from the Branches to the Annual Convention is also recommended by the committee.

The Engineers' Building.—During the past year, the permanent home of the INSTITUTE, occupied jointly with the American Institute of Mining Engineers and the American Society of Mechanical Engineers, has been finished and officially dedicated. Through the medium of the United Engineering Society, as a holding corporation, the American Institute of Electrical Engineers is the owner in perpetuity of one-third of the property numbers 25, 27, 29, 31 and 33 West Thirty-ninth Street, being five city lots, valued at $540,000, purchased by members and friends of the societies, and the building thereon, erected at a cost of $1,050,000, which was the gift of Andrew Carnegie to the founder societies. The corner stone was laid by Mrs. Carnegie, May 8, 1906, when the structure was well advanced. The first INSTITUTE meeting was held in the Auditorium, January 25, 1907, and the offices of the INSTITUTE were occupied February 4, 1907. Inasmuch as the INSTITUTE has acquired a one-third interest in the Engineers' Building, the value of the equity therein has been included as an asset, and appears for the first time in the financial statement.

Building Fund Committee.—The last annual report of the Building Fund Committee stated that on April 30, 1906, the subscriptions had reached a total of $132,434.30 from 644 subscribers, and that $88,238.10 had been received and deposited in the Treasury of the INSTITUTE The Committee reports that at the same date this year the number of subscribers to the fund had risen to 934; that the amount subscribed had reached $163,734.47, and that the amount actually collected and deposited had reached $124,829.17. It will be seen, therefore, that the new subscriptions during the year had reached over $31,000, and that the cash collections during the year had amounted to $36,591. The largest contributors during the year were Mr. George Westinghouse and the associated Westinghouse Companies; namely, the Westinghouse Electric and Manufacturing Company; the Westinghouse Air Brake Company; the Westinghouse Machine Company; Westinghouse, Church, Kerr Company; the Union Switch and Signal Company; the Nernst Lamp Company, and the Cooper Hewitt Electric Company These interests subscribed the munificent sum of $50,000 toward the Building Fund of the three founder societies, and the INSTITUTE received one-third of this amount. The INSTITUTE also received one-third of a similar subscription of $3,500 made by the Allis-Chalmers Company. One of the most encouraging features of the work of the year was the large increase in subscriptions for moderate sums from individual members of the INSTITUTE, nearly 300 names being added to the list. It will be seen that barely $20,000 is now required to complete the amount that the INSTITUTE wishes to collect in order to meet its obligations in this respect, and it is believed that as there are still some 75 per cent. of the members who have not contributed to this fund this amount shall be pledged during the present year. At the same time, it may be pointed out that with nearly 1,000 subscribers to the fund, the Land and-Building Committee is able to report a larger percentage of subscriptions from membership than has ever been secured before in this country in work of the same character in a technical society.

Standardization Committee.—A preliminary report prepared by this committee was presented at the Milwaukee Convention in 1906, where it was very thoroughly discussed, and referred back to the committee for further revision before being submitted to the membership.

The committee has held eleven meetings during the year, and the amended rules have been sent out to such members of the INSTITUTE as were believed to be especially interested in the work. A large number of suggestions have been received, many of which were incorporated in the tentative draft, and the rules are now practically in suitable form to be resubmitted for consideration at the Niagara Falls Convention.

Committee on Bibliography.—By the terms of the Wheeler Deed of Gift, dated May 17, 1901, conveying to the INSTITUTE the Latimer Clark library, a complete catalogue *raisonne* is to be published in the name of the INSTITUTE, reciting the condition of gift and explaining the features of interest of each book, for the convenience and information of members. The preparation of these entries, their verification, and chronological and subject classification, has been completed, and the work is now in the hands of the printer. Arrangements have been made with the Library of Congress and the British Museum for a careful comparative reading of the proofs, and Dr. Silvanus P. Thompson, Dr. G. Hellman and Paul F. Mottelay have also kindly consented to read them critically. The necessary care required to insure accuracy, and render the work authoritative and worthy of the INSTITUTE, involves a considerable amount of time, but it is hoped that the volume will be finished during the present year.

Committee on Papers.—This committee has endeavored to obtain theoretical and practical papers covering the principal branches of the art, and also to make the discussions more valuable, by inviting specialists to take part, after studying the papers in advance. Sixteen papers were presented at New York, and 21 are listed for the Annual Convention at Niagara Falls, in addition to topical discussions.

The committee recommends the preparation of rules and specifications for the guidance of authors in order that suitable cuts may be prepared for publication at a considerable reduction in cost.

The Editing Committee.—Immediately after its appointment, the attention of this committee was directed to the possibility of making the Proceedings a vehicle of information to the membership, of the general work of the INSTITUTE. A conference with the Local Organization Committee brought out the desirability of also including therein a larger proportion of meritorious papers originating through the Branch meetings. This work was undertaken beginning with the October 1906 issue, and many expressions of approval have reached the committee and the Secretary. The change has involved considerable additional labor and expense, but the result has not only been appreciated by the membership, but has made the Proceedings a still more valuable advertising medium.

John Fritz Medal.—On the occasion of the dedication of the Engineers' Building, April 17, 1907, this medal was presented to Alexander Graham Bell, Past-president of the Institute, in accordance with the decision of the John Fritz Medal Board of Award, upon which the INSTITUTE is represented.

Committee on Law.—The attention of this committee has been again devoted to a revision of the Constitution. The failure in the adoption of the draft submitted a year ago, led to the preparation of a revision embodying fewer changes, and the committee had the benefit of the advice of a majority of its members representing the interests of the Branches. The result was satisfactory in enlisting the enthusiastic support of the Branches, many of which made special efforts to induce their members to send in their votes, with such success that over 2,500 ballots have been received.

High Tension Transmission.—A specia meeting was held in New York, March 22, under the auspices of this committee, at which introductions to discussions had been prepared. In addition to the oral discussion, a large number of written contributions were received from members in various parts of the world. The committee has arranged for another meeting at Chicago, May 24, and for a session at the Niagara Falls Convention. Arrangements were made for the publication in a single volume of the earlier work of this committee, the sale of which was very satisfactory, and a second edition is now being printed. The royalties received for these publications will practically cover the expenses of the committee, while the direct professional value of the information thus obtained and disseminated, is strong evidence of the benefits to be derived from the work of the INSTITUTE.

Increase of Membership.—This committee has been continuously occupied during the year in bringing to the attention of non-members actively engaged in electrical work, the increasing prestige of the INSTITUTE, in order that its benefits and usefulness might be more generally appreciated. The results have been very gratifying, as shown by the number of candidates posted each month, reaching a total of about 1,200 during the period covered by the work of this committee. Since January 1, about 40 enrolled students have applied for election as Associates. The cost of carrying on the work of this committee is estimated at about one dollar for each application received.

Membership.—The total membership at the close of last year's report was 3870 classified as follows:

Honorary Members		2
Members		508
Associates		3360
Total May 1, 1906		3870
Elected prior to May 1, 1906, and since qualified		90
Elected May 1, 1906, to April 30, 1907, and qualified		751
Restored to Membership		1
		4712
Deduct—		
Total Deaths	22	
Total Resignations	40	
Dropped as delinquent	129	
		191
Total membership April 30, 1907		4521

The membership April 30, 1907, is classified as follows:

Honorary Members	2	
Members	536	
Associates	3983	
Total		4521

Associates Elected.—The Associates elected during the year, May 1, 1906, to April 30, 1907, and their present status is as follows:

Qualified and now Associates	751
Elections cancelled	2
Not qualified on April 30	196
Total elections	949

Resignations.—The following Members and Associates have resigned in good standing during the year:

Members.—A. E. Childs, P. Dawson.

Associates.—W. Ambler, F. F. Bahnson, S. R. Barton, G. R. Bott, W. F. Bouché, Orion Brooks, E. M. Burgess, H. S. Burroughs, E. L. Caldwell, F. R. Chambers, R. E. Cunningham, C. C. Curtis, W. H. Dopp, C. A. Fernald, George S. Gibbs, J. M. Gilmore, Phillip Hamlin, W. E. Hopton, C. E. Harthan, M. C. Hull, J. E. H. Hyde, J. E. Ives, P. H. Lombard, W. K. Leggett, Felix Levy, John Lind, W. W. Mason, Jr., J. A. L. Möller, G. E. McCarn, W. E. Moody, G. W. Nistle, F. R. School-field, A. V. Sedgwick, R. C. Shaal, Angus Sinclair, F. S. Stitt F. R. Spiller, C. H. Tyndall. Total, 40.

Deaths.—There have been during the year the following deaths:

Members.—A. V. Abbott, J. B. Cahoon, F. L. Freeman, Eugene Griffin, F. E. Jackson, J. E. Lloyd.

Associates.—C. A. Bragg, Louis Cassier, E. E. Davis, K. G. Gillberg, H. W. Goode, A. E. Hayes, W. C. Johnson, W. J. Johnston, B. E. Mercil, K. Okamota, C. F. Parker, C. L. Spier, A. H. H. Trott, F. Townsend, L. C. Whitehouse, W. A. Whittlesey. Total, 22.

Dropped as delinquent during the year, 129.

The average receipts and disbursements *per capita* for the past seven years, are shown in the following table:

RECEIPTS AND DISBURSEMENTS PER YEAR PER MEMBER.

During each fiscal year for the past seven years.

Year	**1901**	**1902**	**1903**	**1904**	**1905**	**1906**	**1907**
Membership, April 30th, each year	1260	1549	2230	3027	3460	3870	4521
RECEIPTS PER MEMBER:							
Entrance Fees	$0.61	$1.16	$1.59	$1.65	$0.83	$0.75	$0.90
Dues	8.61	10.06	9.01	9.33	9.30	9.47	8.95
Transactions, Sales, Advertising	1.03	1.54	1.79	2.11	1.70	2.15	1.81
Badges	.18	.26	.35	.39	.28	.27	.30
Interest	.12	.24	.21	.18	.21	.13	.25
	$10.55	$13.26	$12.95	$13.66	$12.32	$12.77	$12.21
DISBURSEMENTS PER MEMBER:							
Transactions	$2.83	$3.50	$4.67	$3.43	$3 77	$3.33	$2.83
Salaries	2.49	2.78	2.49	2.50	2.20	2.64	2.53
Meeting Expenses, incl. Branches	1.05	1.13	.87	1.16	.82	.68	.68
Housing	.94	.94	.65	.79	.75	.68	1.33
Library, incl. Rent and Salaries	.55	1.85	1.38	1.39	.81	.69	1.37
Postage	.46	.51	.69	.66	.66	.58	.59
Stationery and Miscel. Printing	.39	.53	.96	1.01	.70	.78	.85
General Expenses	.33	.59	.52	.45	.54	.29	.43
Badges	.16	.19	.27	.35	.25	.22	.29
Express	.15	.15	.15	.28	.22	.23	.28
Advertising						.36	.30
Office Fittings							.14
Total	$9.35	$12.17	$12.65	$12.02	$10.72	$10.48	$11.62
Credit Balance per Member	$1.20	$1.09	$0.30	$1.64	$1 60	$2.29	.59

LAND, BUILDING AND ENDOWMENT FUND.

Receipts.	
Before appointment of Committee	$ 6,100.00
Collected by Committee	123,361.67
Interest on balances	2,910.38
	$132,372.05

Disbursements.	
Paid United Engineering Society, acct. Contract	$ 8,000.00
Paid United Engineering Society, acct. Mortgage	9,000.00
Paid United Engineering Society, acct. Interest	10,620.00
Paid for Fittings and furniture of Engineers' Building	3,924.04
Expenses of Committee	4,681.94
Balance in bank May 1, 1907	96,146.07
	132,372.05

Note:—

Collected by Committee, as reported above	$123,361.67
Collected by Committee deposited since May 1	1,467.50
Total collected by Committee as per the Committee's report	124,829.17

New York, May 20, 1907.

Dr. Samuel Sheldon,
President of the American Institute of Electrical Engineers.

Sir: Pursuant to the provisions of the Constitution, the Committee on Finance has during the year exercised supervision over the financial affairs of the Institute. It has considered all bills and approved for payment such as constituted a proper charge against the Institute.

It has considered and reported upon specific appropriations, and has made special reports upon various matters referred to it by the Board of Directors.

As provided by the Constitution, it has employed an expert accountant to audit and report upon the accounts of the Institute; and this report made by Messrs. Peirce, Gimson and Co., certified public accountants, has been approved by the Committee on Finance, and is transmitted herewith.

Very truly yours,
J. J. Carty,
Chairman Committee on Finance.

GENERAL FINANCIAL STATEMENT.

Mr. John J. Carty,
Chairman Committee on Finance.

Sir: In accordance with your instructions, we have audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1907.

The results of this examination are presented in four exhibits, attached hereto, as follows:

Exhibit A. Balance sheet April 30, 1907.

Exhibit B. Receipts and disbursements for general purposes for year ended April 30, 1907.

Exhibit C. Receipts and donations for designated purposes, also expenditures on same for year ended April 30, 1907.

Exhibit D. Condensed cash statement.

We beg to present attached hereto our certificate to the aforesaid exhibits.

Yours very truly,
Peirce, Gimson & Co.,
Certified Public Accountants.

Mr. John J. Carty,
Chairman Committee on Finance.

Dear *Sir*:

Having audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1907, we hereby certify that the accompanying Balance Sheet is a true exhibit of its financial condition as of April 30, 1907, and that the accompanying statements of Cash Receipts and Disbursements are correct.

Peirce, Gimson & Co.,
Certified Public Accountants.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

BALANCE SHEET APRIL 30, 1907.

EXHIBIT A.

ASSETS.		
CASH:		
Land, Building and Endowment fund	$96,146.07	
Carnegie (Library) fund	3,529.60	
General Library fund	237.00	
Compounded Membership fund and Interest	5,465.34	
*Mailloux fund	1,007.55	
International Electrical Congress of St. Louis, 1904, Library fund	2,140.10	
	$108,525.66	
*General cash in bank	17,624.24	
Secretary's petty cash on hand	500.00	$126,649 90
United States Government Bonds 3s, 1918	8,000,00	
Premium on Bonds	320.00	
		8,320.00
Equity in Societies Building (25 to 33 West 39th Street)	350,000.00	
One-third cost of land (25 to 33 West 39th Street)	180,000.00	
		530,000.00
Library volumes and fixtures	24,174.76	
Transactions	4,352.75	
Office furniture and fixtures	5,114.30	
Works of art, paintings, etc.	2,300.00	
Badges	210.25	
		36,152.06
ACCOUNTS RECEIVABLE:		
Members for past dues	8,966.60	
Members for entrance fees	295.00	
	9,261.60	
Miscellaneous	145.60	
Subscriptions	24.90	
For advertising	1,661.47	
		11,093.57
United Engineering Society, assessment, advance payment May and June		2,222.22
Total Assets		714,437.75

* The Farmers' Loan and Trust Co. deposit account includes $7.55 of the Mailloux Fund.

LIABILITIES AND SURPLUS.		
FUNDS:		
Land, Building and Endowment Fund	$96,146.07	
Carnegie (Library) Fund	3,529.60	
General Library Fund	237.00	
Compounded Membership Fund and interest	5,465.34	
Mailloux Fund	1,007.55	
International Electrical Congress of St. Louis, 1904, Library Fund	2,140.10	
	$108,525.66	
Reserve fund (U. S. Govt. Bonds)	8,320.00	
Total		$116,845.66
United Engineering Society (for cost of land)		171,000.00
Total liabilities		$287,845.66
SURPLUS:		
In cash	$18,124.24	
In property and accounts receivable	408,467.85	
		426,592.09
Total liabilities and surplus		$714,437.75

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Receipts and Disbursements for General Purposes for Year Ended April 30, 1907.

Exhibit B.

Receipts.		
Entrance Fees	$4,075.00	
Current Dues	35,653.25	
Past Dues	2,310.00	
Advance Dues	219.00	
Students' Dues	2,256.00	
Transfer Fees	395.00	
Badges	1,367.50	
		$46,275.75
Sales, Transactions	915.07	
Subscriptions, Proceedings	661.98	
Advertising	5,597.35	
Binding	89.80	
Exchange	14.59	
Interest:		
U. S. Govt. Bonds	240.00	
Bank Balances	865.10	
Royalty	239.75	
Sundries (refund)	13.32	
Insurance Rebates	22.13	
Rent (sub-tenant)	250.00	
		8,909.09
Total		$55,184.84

Disbursements.		
Stationery and Printing	$3,830.80	
Postage	2,669.83	
General Expenses	1,972.26	
Meeting Expenses	1,861.13	
Branch Meetings	1,196.96	
Badges	1,354.30	
Salaries	9,407.40	
Rent	2,645.04	
Office Furniture	652.39	
		$25,590.11
Proceedings—Transactions:		
Printing	6,624.79	
Salary	2,000.00	
Engraving	1,446.97.	
Volumes	3,299.32	
Electrotyping	689.29	
Binding	704.79	
Express	1,272.76	
Advertising Commissions	1,380.00	
		$17,417.92
Library:		
Rent	1,475.04	
Librarian salaries	887.20	
Library Insurance	106.35	
Miscellaneous	395.66	
		2,864.25
United Engineering Society		6,666.66
Total		$52,538.94
Excess receipts over disbursements deposited in general fund		2,645.90
		$55,184.84

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Receipts and Donations for Designated Purposes also Expenditures for Year Ended April 30, 1907.

Exhibit C.

Receipts.	
Land, Building and Endowment fund, Donations, Interest, etc	$37,062.46
Carnegie (Library) Fund, Interest	119.08
General Library Fund, Interest	7.08
Life Membership Fund	578.37
International Electrical Congress of St. Louis, 1904, Library Fund	73.04
Mailloux Fund, Interest	30.00
Total	$37,870.03

Expenditures.	
Land, Building and Endowment Fund	$21,617.01
Carnegie (Library) Fund	541.85
General Library Fund	2.64
Mailloux Fund	23.20
Total Expenditures	$22,184.70
Deposited to credit of their respective fund accounts	15,685.33
Total	$37,870.03

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Condensed Cash Statement.

Exhibit D.

Cash on deposit April 30th, 1906	$107,818.67	
Secretary's petty cash April 30th, 1906	500.00	
	$108,318.67	
Receipts for general purposes, Exhibit "B"	55,184.84	
Receipts for designated purposes, Exhibit "C"	37,870.03	
		$201,373.54
Disbursements for general purposes, Exhibit "B"	$52,538.94	
Expenditures for designated purposes, Exhibit "C"	22,184.70	
		$74,723.64
Balance on hand April 30th, 1907		$126,649.90
On deposit for designated purposes, Exhibit "A"	$108,525.66	
On deposit for general purposes, Exhibit "A"	17,624.24	
Secretary's petty cash, Exhibit "A"	500.00	
		$126,649.90

PROPERTY ACQUIRED DURING THE YEAR.

(Reported as directed by the Constitution.)

Office Furniture and Fixtures	$4328.86
Library Books and Binding	500.00
Engineering Societies Building, Equity	350,000.00

All outstanding bills rendered prior to May 1st, 1907, have been paid.

Respectfully submitted for the Board of Directors.

Ralph W. Pope, *Secretary.*

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25, 1907.

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(*Subject to final revision for the Transactions.*)

THE HEATING OF COPPER WIRES BY ELECTRIC CURRENTS

BY A. E. KENNELLY AND E. R. SHEPARD

In August 1889, a report was made by one of the present writers[1] to the Edison Electric Light Co., on "The Heating of Conductors by Electric Currents." The report was published in the minutes of the convention of the Association of Edison Illuminating Companies, at Niagara Falls, August 1889. It contained a large number of measurements of the temperature elevations of active conductors supported in wooden moulding, and in free air, within doors and without. A further report was made in 1893[2] upon the temperature elevations of electric-light cables. The research reported in the present paper has been undertaken to extend the scope of the above measurements, and also to increase the precision of the results previously obtained. In the measurements of 1889 and 1893, above referred to, the temperature-coefficient of resistivity of copper wires was taken as 0.388 per cent. per degree centigrade of temperature elevation; whereas it is now taken by the American Institute of Electrical Engineers as 0.42 per cent. per degree centigrade from and at 0° cent.[3] Again, the law of thermal radiation employed was that of Dulong and Petit;[4] whereas the law of radiation generally adopted at this time is that of Stefan.[5]

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[1] The Heating of Conductors by Electric Currents, by A. E. Kennelly, *The Electrician*, Dec. 13th, 1889, Vol. XXIV, p. 142; *The Electrical World*, Vol. XIV, No. 21, p. 336, Nov. 23, 1891.

[2] The Carrying Capacity of Electric Cables, Submerged, Buried or Suspended in Air, by A. E. Kennelly, Minutes of the Ninth Annual Meeting Association of Edison Illuminating Companies, 1893, p. 79.

[3] Trans. Am. Inst. Elect. Engineers, Vol. XIX, p 1082, June, 1902. Standardization Report.

[4] Annals de Chemie et de Physique, 1817, Vol. VII.

[5] Wien Akad. Ber., 1879, LXXIX, pp. 391–428.

Although these changes in physical data and constants do not greatly affect, from an engineering standpoint, the results previously obtained; yet it seemed desirable to make a new series of measurements[6] and deduce their results with the aid of the most recent data. It is the object of this paper to describe the new measurements, so far as relates to wires in water, soil, or wooden moulding, leaving the measurements on wires in air to some future occasion.

Method of Determining Temperature Elevations. The copper conductor under test had a length of from 2 to 6 metres (6.56 to 19.69 feet). Pressure wires were soldered to it near its ends. The resistance of the conductor between these pressure wires was determined, first, when cool, *i.e.*, at the temperature of the surrounding air, and second after having been heated by an electric current of measured strength. The increase in the resistance of the conductor enabled its increase in temperature to be determined by the formula:

$$R_t = R_0 (1 + 0.0042\, t) \qquad \text{ohms} \qquad (1)$$

where R_0 is the resistance of the conductor at 0° C., and R_t its resistance at t° C.

Method of Measuring the Resistance of the Copper Conductors. The resistances of the copper conductors under test were measured by differential galvanometer; *i.e.*, by connecting one coil of a differential galvanometer to the pressure wires on the tested conductor, and the other coil to the terminal of a German-silver constant resistance of determined amount, in circuit with the tested conductor. Extra resistance was inserted in the circuit of the coil of preponderating current until the galvanometer deflection was zero, or the two currents differentially balanced. Under these conditions, the resistance of the tested conductor became known in terms of the constant German-silver resistance. As the tested conductor increased in temperature, its changes of resistance could readily be observed and followed, by noting the change in the balancing resistance.

The electrical connections employed are indicated diagrammatically in Fig. 1. A separate motor-driven low-voltage direct-current dynamo Y, of 3 kw. capacity (300 amperes at

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[6] The research was carried on at Pierce Hall, Harvard University and a report thereon formed the subject of a thesis for the degree of A.M. by E. R. Shepard, entitled : "The Heating of Copper Wires by Electric Currents," 1906.

10 volts), was connected by stout leads to the conductor *C C*, under test, in another room, through a grid resistance *D* of German-silver wires, and a regulating resistance *R*. The current strength in the circuit was measured by the Weston ammeter *A*, and adjusted partly by varying the resistance *R*, and partly by varying the shunt field rheostat *F*. The differential galvanometer *G* has one coil connected to pressure wires on the standard grid resistance *D*, and the other coil to pressure wires on the tested conductor *C C*. An adjustable resistance *r* was inserted in one or the other of the two galvanometer circuits as occasion required, in order to secure a differential balance. Switches in the main circuit and in the galvanometer circuits have been omitted from the diagram.

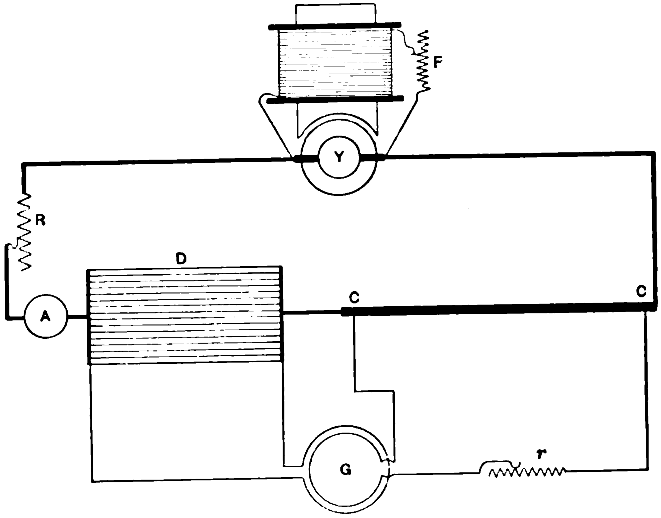

FIG 1—Electrical connections in tests

The German-silver Wire Grid. The grid was made up in such a manner as to carry the strongest testing currents used, with a relatively small rise of temperature, and was made of metal having a relatively small temperature-coefficient of resistivity, so as to maintain a practically constant resistance during the tests. It consisted of an open wooden frame about 2 metres long (6.56 feet) by 1 metre broad (3.28 feet), containing 65 parallel wires of German-silver supported freely in air, each 0.129 cm. (0.0508 in.) in diameter, and 183 cm. (6 feet) in length. These wires were divided into three permanently connected groups of 25, 20, and 20 wires respectively, in such a manner that the groups could be connected either in series, or in parallel, for different resistances and current-carrying capacities. When the three groups were connected in series, the total resistance of the grid between pressure wires was 0.0441 international ohm. When the three groups were connected in parallel, the resistance of the grid between pressure wires was 0.0044 international ohm. Intermediate series-parallel groupings and resistances were also used in some of the tests.

The resistance of the grid was frequently measured and checked. One such check measurement was ordinarily made with each successive conductor test. The grid resistance was measured by using the same connections as are shown in Fig. 1; but with a standard platinoid strip resistance substituted for the conductor *C C*. Two such standard strips were employed, with resistances of 0.015125 and 0.03053 international ohms respectively. These standard resistances were in their turn checked and calibrated by comparison with a standard 0.01 international ohm loaned by the Jefferson Physical Laboratory. All the measurements of resistance stated in this paper are in terms of the international ohm, and are ultimately referred to this 0.01 ohm standard.

The Differential Galvanometer. The galvanometer employed was of the Edelmann type, having a steel split-bell suspended magnet, swinging in a copper well, and two separate coils of silk-covered wire placed on opposite sides of the suspended magnet. These coils were wound specially for these tests with silk-covered copper wire, each coil having a resistance of about 1800 ohms. The resistances of the coils, being subject to change with variation of room temperature, were frequently measured during extended tests. The differential condition was also frequently checked.

The sensitiveness of the galvanometer as used in the tests was 0.143 microampere for 1 mm. scale deflection at the range used of 140 cm. Referred to a range of 1 metre, this would be 0.20 microamperes per mm. scale-reading deflection, or the current sent by 1 volt through 5 megohms, including both coils.

The periodic time of the galvanometer swing was 5.17 seconds. The damping ratio of successive opposite elongations was 2.465; or the Naperian logarithmic decrement of successive opposite elongations 0.9027. Four complete swings, executed in 20.7 seconds, sufficed to reduce the deflection to $\frac{1}{1370}$th part; or, for practical purposes, to rest.

When balance is obtained on the differential galvanometer G in Fig. 1, we have

$$x = R_{\mathrm{D}} \frac{G_{\mathrm{C}}+r}{G_{\mathrm{D}}} \qquad \text{international ohms} \qquad (2)$$

where R_{D} is the resistance of the grid, G_{C} and G_{D} the resistances of the two galvanometer coils respectively, including leads, and r the resistance added to the circuit of the conductor $C\,C$, whose resistance is x ohms. In all the experiments, G and r were measured by a B.A.-unit Wheatstone bridge, in B.A. ohms. As, however, only the ratio $\frac{G_{\mathrm{C}}+r}{G_{\mathrm{D}}}$ appears in formula (2) this does not affect the evaluation of x in international ohms.

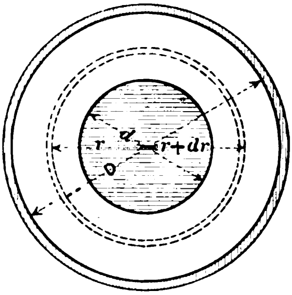

FIG. 2—Diagrammatic cross-section of lead-covered insulated wire

Theory of the Temperature Elevation of an Active Conductor Cooled Entirely by Thermal Conduction. The simplest case of the heating of an active electric conductor is that of a uniform cylindrical wire carrying a steady direct current, and covered with a uniform concentric coating of rubber or other insulator, the external surface of which, either with or without a leaden sheath, is kept at a uniform known temperature by being immersed in a tank of running water.

In Fig. 2 the wire of diameter d cm, is covered by insulating material to a total diameter of D cm. The external sheath of lead is so good a thermal conductor that, for all practical purposes, its temperature is $t°$ C. at all points. The internal wire of copper is likewise so good a thermal conductor that its temperature at all points is $t+\theta$ degrees centigrade. This means that after a sufficiently long application of a direct current through the wire to establish a steady thermal condition, there is a difference of temperature of θ° C. between the internal and external surfaces of the insulating cylinder.

If we consider one unit length or linear centimetre of the conductor, the thermal resistance, to the radial flow of heat, offered by any cylindrical element of the insulator between the radii r and $r+dr$ centimetres will be

$$d\mathcal{R} = \frac{dr}{2\pi r}\sigma \qquad \text{thermal ohms} \qquad (3)$$

where σ is the thermal resistivity of the insulator at its working temperature, and is numerically equal to the thermal resistance of a cubic centimetre of the substance between any pair of opposed faces, dr is the thickness of the elementary cylinder, and $2\pi r$ the surface area of this cylinder in unit length. The total thermal resistance between wire and sheath will be the sum of all the resistances of the elementary cylinders between the internal diameter d and the external diameter D; or

$$\mathcal{R} = \frac{\sigma}{2\pi}\log_\varepsilon \frac{D}{d} \qquad \text{thermal ohms} \qquad (4)$$

in a linear centimetre of the insulator.

If ρ_t is the electric resistivity of the wire at the initial temperature t° C., which is also the temperature of the external surface, the electric resistance of the wire per linear cm. is

$$R_t = \frac{4\rho_t}{\pi d^2} \qquad \text{ohms at } t^\circ \text{ C.} \qquad (5)$$

and at the temperature finally reached by the wire $(t+\theta)^\circ$ C., the resistance is

$$R_{t+\theta} = \frac{4\rho_t(1+a\theta)}{\pi d^2} \qquad \text{ohms} \qquad (6)$$

where a is the temperature coefficient of resistivity of the wire for the initial temperature t° C., and[7] is equal to $\frac{1}{238.1+t}$.

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[7] The Resistivity Temperature—Coefficient of Copper. *Electrical World*, June 30, 1906.

The total flow of heat, or thermal current, passing radially through a linear centimetre of the insulator in the steady state, with a current of I amperes in the wire, is

$$\mathcal{J} = I^2 R_{t+\theta} \qquad \text{watts per cm.} \qquad (7)$$

This thermal energy current follows a law similar to Ohm's law, or

$$\mathcal{J} = \frac{\theta}{\mathcal{R}} \qquad \text{watts per cm.} \qquad (8)$$

and by (4)

$$\mathcal{J} = \frac{\theta}{\frac{\sigma}{2\pi} \log_\varepsilon \frac{D}{d}} \qquad \text{watts per cm.} \qquad (9)$$

and by (6)

$$\frac{4 I^2 \rho_t (1 + a\theta)}{\pi d^2} = \frac{\theta}{\frac{\sigma}{2\pi} \log_\varepsilon \frac{D}{d}} \qquad \text{watts per cm.} \qquad (10)$$

Consequently

$$\frac{\theta}{1 + a\theta} = \frac{2\sigma\rho_t \log_\varepsilon \frac{D}{d}}{\pi^2 d^2} \cdot I^2 \qquad \text{degrees C.} \qquad (11)$$

or

$$\frac{\theta}{1 + a\theta} = K I^2 \qquad \text{degrees C.} \qquad (12)$$

where K is a constant for a conductor of given dimensions, if the thermal resistivity σ may be taken as constant. We know that σ may vary with temperature in many substances, but there is evidence in this report to show that it is substantially constant in various insulating substances, between the limits of 0° C. and 100° C.

Equations (11) and (12) express the relation between the final temperature of any wire carrying a continuous current, under the conditions of Fig. 2. Equation (12) must apply to any uniform wire carrying a continuous current in the steady state, no matter how many successive layers of insulator there may be, provided only that the heat escapes by conduction, as distinguished from radiation and convection, and also provided that the thermal resistivities of the successive insulators may be taken as constant within the range of their working temperatures. Formula (12) applies, therefore, to all buried continuous-current cables, and also to insulated wires in water. It also applies fairly well to insulated wires in wooden moulding. It is the fundamental equation of electric heating of concealed wires, carrying continuous currents, from the temperature t° C. of surrounding objects to the final temperature $(t+\theta)^\circ$ C., when the temperature elevation θ does not exceed, say, 100° C.

The temperature coefficient a varies with the initial temperature t° C.

For an initial temperature $t = 12^\circ$ C. $a = 0.004$
" " " " $t = 18^\circ$ C. $a = 0.0039$
" " " " $t = 25^\circ$ C. $a = 0.0038$

If we take $t = 18^\circ$ C., as an average initial temperature in practice, equation (12) becomes:

$$\frac{\theta}{1+0.0039\,\theta} = K\,I^2 \qquad \text{degrees C.} \qquad (13)$$

This means that the final temperature elevation θ of a wire carrying a continuous current I amperes, increases somewhat more rapidly than the square of the current, and the deviation from the square is greater, the greater the temperature elevation. This relation may also be rendered evident in a graphical way as follows: Logarizing both sides of (13), we have

$$\log\theta - \log\,(1+0.0039\,\theta) = 2\log I + k \qquad (14)$$

where $k = \log K$, and is a constant for a given size of wire and succession of insulating coatings.

If we plot log I (Fig. 3) against log θ, we draw the straight line $e\,f$, making with $e\,x$ an angle 63° 26′ whose tangent is 2. This represents the locus of log θ. We then lay off a curved line $A\,B\,C\,D$, such that its distance from the straight line $E\,F$ is everywhere $\frac{1}{2}$ log $(1+0.0039\,\theta)$. By deducting these distances from $e\,f$, we obtain the final curve $a\,b\,c\,d$, which, by (14), is the graph of log θ in relation to log I. Joining the points a and d by the broken straight line $a\,d$, we find that this is inclined to the $e\,x$ axis by an angle whose tangent is 2.289; so that the final temperature elevations of 10° and 100° C., in accordance with (13), represent an increase of temperature in the ratio of $I^{2.289}$, or the exponent of 2.289 for the currents.

In other words, judging from these two observations alone, it would appear that the temperature increased as the 2.289th power of the current. If, however, we consider the points *a* and *c* on the curve, corresponding to the temperature elevations 10° and 50° C. respectively, the dotted straight line *a c* makes with *e x* an angle whose tangent is 2.19. This represents an increase of temperature elevation according to $I^{2.19}$, so far as concerns these particular points.

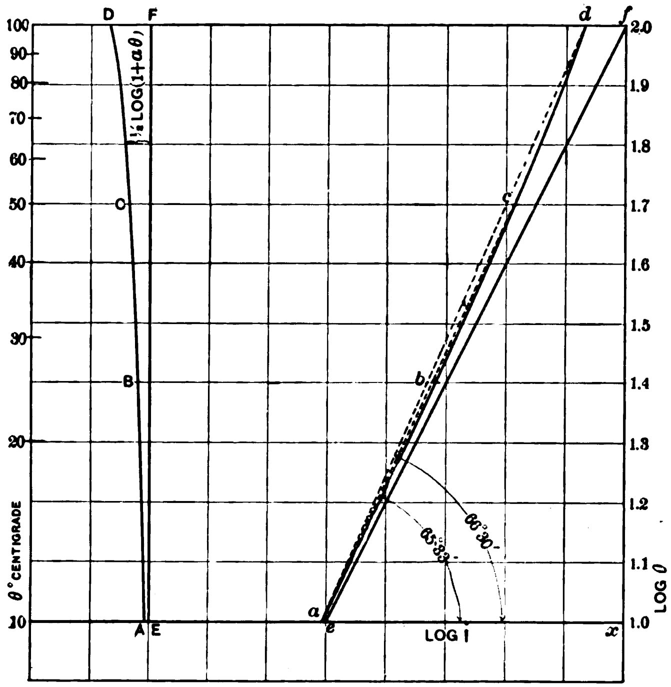

FIG. 3—Diagram indicating the graphical relation between current and temperature elevation when plotted on logarithm paper

If then we plot $\log \theta$ against $\log I$, in accordance with (13) and (14), the graph will be a flat curve commencing at an angle $\tan^{-1} 2$, and bending slowly upward in such a way that on the 10°–50° range, θ varies approximately as $I^{2.2}$; whereas taking the 10°–100° range, θ varies approximately as $I^{2.3}$. The exact value of the exponent will depend both on t and on θ. If we limit our enquiry to temperature elevations of 50° C., we may expect to find the observations on logarithm paper fall nearly on a straight line, making an angle $\tan^{-1} 2.2$ with the axis of abscissas. If, however, we extend the range of observation to $\theta = 100°$ C., the mean straight line on logarithm paper will be somewhat steeper, and approach the angle $\tan^{-1} 2.3$.

Thus if $t = 6°$ C. $\theta \propto I^{2.304}$ between $\theta = 10$ and $100°$ C.
if $t = 12°$ C. $\theta \propto I^{2.296}$ " " = " " "
if $t = 18°$ C. $\theta \propto I^{2.289}$ " " = " " "
if $t = 25°$ C. $\theta \propto I^{2.282}$ " " = " " "

For practical purposes, therefore, with temperature elevations averaging about 50° C., we may regard the theoretical graph of temperature elevation against current strength on logarithm paper as conforming fairly well with a straight line making an angle $\tan^{-1} 2.2$ or, $65° 33'$, with the axis of abscissas, or

$$\log \theta = 2.2 \log I + k \qquad (13)$$

corresponding to

$$\theta = K I^{2.2} \quad \text{deg. C.} \qquad (14)$$

Measurements of Temperature Elevation in Rubber-Covered Wires. Five sizes of rubber-covered and braided code wire, all from the same factory, were used in these tests, immersed in running water. The dimensions of these wires are given in the following table:

TABLE I.
DIMENSIONS OF RUBBER-COVERED AND BRAIDED CODE WIRES

Size of Wire A. W. G.	Diameter of Copper Wire		Diameter over Rubber		Diameter over Braid	
	cm.	Inch	cm.	Inch	cm.	Inch
8	0.3263	0.1285	0.6348	0.25	0.7365	0.290
10	0.2552	0.1005	0.4952	0.195	0.6223	0.245
12	0.2032	0.0800	0.432	0.170	0.5715	0.225
14	0.1626	0.064	0.3987	0.157	0.482	0.190
16	0.1296	0.051	0.2895	0.114	0.381	0.150

A length of about 5 metres of each of the above wires had pressure wires soldered to the conductor, and was then immersed in running water during the test. The time required to attain a practically steady temperature after the application of a continuous current was only about 5 minutes under these conditions. Table II gives the recorded observations in the case

TABLE 11.

TESTS OF NO. 16 A. W. G. RUBBER COVERED AND BRAIDED WIRE IMMERSED IN RUNNING WATER AT 5° C. DISTANCE BETWEEN PRESSURE WIRES 550 CM.

Time from Start, min.	Current Strength, amp.	Res: of Galvr. Coils B.A.U.		Res: added to wire B.A.U.	Ratio of Increase	Res: of wire Int. ohms.	θ Temp. Elevation of wire, ° C.	Res. of Standard Grid Int. ohms	$R_{t+\theta}$ Res. of wire per cm. Int. microhms	I watts per cm. $I^2 R_{t+\theta}$	$\mathcal{R}$ Thermal Res. of linear cm.	t Temp. of water ° C.
		C	D									
0	3	1776	1853	1200	1.	0.07081		0.04409	128.7			5
7	30	"	"	1292	1.031	0.07300	7.54	"	132.7	0.1194	63.15	"
15	35	"	"	1330	1.0435	0.07390	10.58	"	134.3	0.1645	64.31	"
22	40	"	"	1370	1.0570	0.07486	13.86	"	136.0	0.2176	63.69	"
26	45	"	"	1420	1.0738	0.07604	17.94	"	138.2	0.2799	64.09	"
33	50	"	"	1477	1.0930	0.07740	22.61	"	140.7	0.3517	64.27	"
										Mean	63.9	

of the No. 16 wire, and is a fair example of the measurements taken collectively. The second column gives the current strength steadily applied. The initial balance was obtained by a brief application of a current of 3 amperes. A current of 30 amperes was then applied at the start and the balance again observed after 7 minutes. The current was then increased to 35 amperes for 8 minutes, and so on.

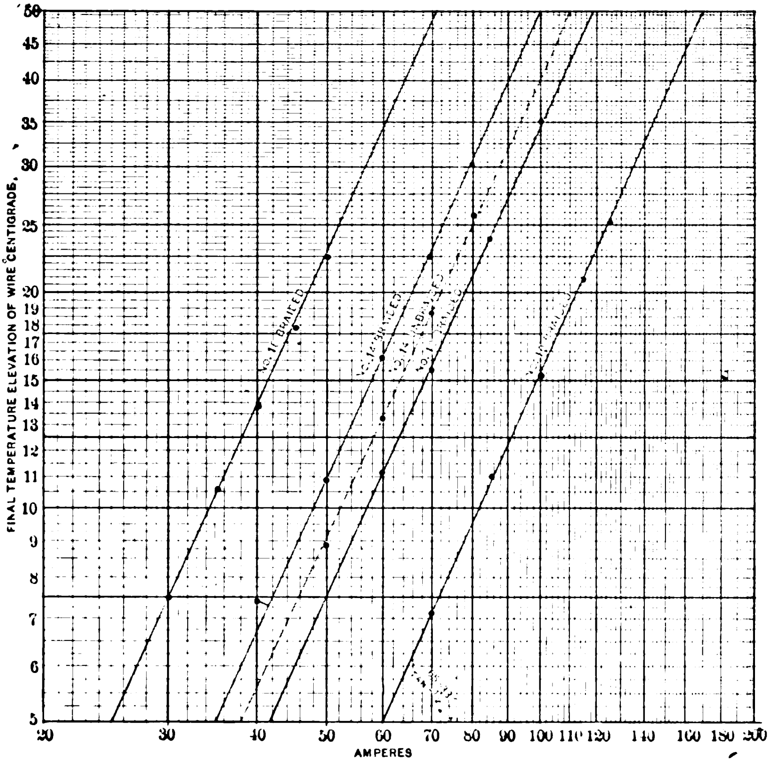

FIG. 4—Observed temperature elevations of different sizes of Code rubber-covered wires in water

The last column but one gives the thermal resistance of a linear centimetre of dielectric and braid. Its mean value is 63.9 thermal-ohm-cm.

The temperature elevations θ in the above table are plotted as black circles in Fig. 4 on logarithm paper. The straight line marked No. 16 braided, is drawn through the 30-ampere point to make an angle of 65° 33′, or $\tan^{-1} 2.2$, with the axis of abscissas. This straight line corresponds, therefore, to formulas (13) and (14) derived from the theory already outlined. The agreement of the observation points with the theoretical straight line is seen to be satisfactory.

Table III contains all the final temperature elevations computed from the measurements made on the samples of wire scheduled in Table I, and also contains the corresponding thermal resistances in one linear centimetre. The final temperature elevations are all plotted in Fig. 4 as ordinates, against currents as abscissas, to logarithmic scales, the straight lines being drawn parallel to each other according to formulas (13) and (14). With the exception of one doubtful observation on the No. 14 braided wire, all the points are in satisfactory conformity with these parallel straight lines, thus confirming the theory already outlined, as expressed in formulas (11), (12), (13) and (14).

TABLE III

TEMPERATURE ELEVATIONS OF DIFFERENT SIZES OF RUBBER-COVERED WIRES IN WATER

Current Amp.	I No. 16 Braided $t=5°$		II No. 14 Braided $t=5.5°$		III No. 14 Unbraided $t=5°$		IV No. 12 Braided $t=4.5°$		V No 10 Braided $t=4.5°$	
	θ Temp. Elev.	$\mathcal{R}$ Thermal Res.	θ Temp. Elev.	$\mathcal{R}$ Thermal Res.	θ Temp. Elev.	$\mathcal{R}$ Thermal Res.	θ Temp. Elev.	$\mathcal{R}$ Thermal Res.	θ Temp. Elev.	$\mathcal{R}$ Thermal Res.
30	7.54	63.15								
35	10.58	64.31								
40	13.86	63.69	7.4							
45	17.94	64.09								
50	22.61	64.27	10.91	52.88	8.8	42.93				
60			16.22	53.47	13.3	44.31	11.16	59.45		
70			22.46	53.12	18.6	44.56	15.43	59.37	7.16	45.8
80			30.32	53.17	25.86	46.15				
85							23.77	60.11	11.11	47.46
100							35.16	61.59	15.26	46.32
115									20.86	46.87
125									25.13	47.03
Means		63.90		53.21		44.50		60.13		46.70

A comparison of Columns II and III in Table III, or of the corresponding lines in Fig. 4, shows that the addition of a coating of cotton braid about 0.4 mm. (1/64 inch) increased the temperature of the No. 14 wire about 2° C. with 50 amperes, and about 4.5° C. with 80 amperes, the wire being immersed in water in each case. The braid also added 8.7 thermal-ohm-cm. (3.76 thermal-ohm-inches) to the linear thermal resistance of the covering of this particular wire.

Taking the internal and external diameter of the braiding of No. 14 wire from Table I as 0.3987 cm. (0.157 in.) and 0.482 cm. (0.190 in.) respectively, we obtain by formula (4) the thermal resistivity $\sigma = 287.1$ thermal-ohm-cm., when soaked in water at 5° C.

With this thermal resistivity for the soaked braid, the thermal resistivity of the rubber covering on the wires was deduced, as in the following table:

TABLE IV.

THERMAL RESISTANCES AND RESISTIVITIES OF WIRE COVERINGS

Size Wire A. W. G.	Thermal Resistance of Wire in a linear centimetre			Thermal resistivity	
	rubber + braid	braid	rubber	braid	rubber
	ohms-cm.	ohms-cm.	ohms-cm.	ohms-cm.	ohms-cm.
10	46.7	10.47	36.23	287.1	343.5
12	60.13	12.82	47.31	"	394.4
14	53.21	8.71	44.50	"	311.6
16	63.90	12.51	51.39	"	401.5
				Mean	387.8

The mean resistivity of the "rubber" covering of these wires was therefore 387.8 thermal-ohm-cm.; but since this material in code rubber-covered wires is largely composed of filling material other than rubber, different compositions are likely to vary considerably in thermal resistivity.

The thermal resistance $\mathcal{R}$ in a linear centimetre of any size of such braided and rubber-covered wire is readily determinable from the dimensions of the wire and the above mean thermal resistivities, by the aid of formula (4) and the probable temperature elevation for a given current strength then follows from formula (8). If the wire is buried in the ground, the additional thermal resistance of the ground must be added, taking into account the heat that may be liberated by any active wires buried in the same trench or conduit.

Heating of Code Rubber-Covered Wires in Wooden Moulding. When rubber-covered wires are laid in wooden moulding, the heat generated by continuous currents in the wire has to pass in succession through the rubber, dry braiding, air-space, wooden moulding, and finally through wall, ceiling or air. Owing to the complex geometrical relations of these successive thermal resistances, they are not easy to compute, even when the thermal resistivities of the respective substances are correctly stated. The best plan is, therefore, to measure the thermal resistance of the series combination under different conditions such as occur in practice, and then to tabulate the safe carrying capacity of such wires from the measurements directly, as in the report of 1889, above referred to.

The moulding used in the tests here reported was of pine wood, of the cross-section shown in Fig. 5. Its length was 3.86 metres (12.67 feet) and its weight was 720 gm. per metre (0.48 lb. per foot). It was lightly nailed down flat upon the wooden floor of the testing room. The wire to be tested was laid in a loop along the moulding so as to occupy the two outside grooves, as indicated in the figure, leaving the middle groove vacant. Pressure wires were connected to the test wire at points about 5 metres apart. The temperature elevation became substantially constant thirty minutes after the application of each testing current strength. The initial temperature t° C. varied from 19.0° C. to 21.0° C. in the different series of tests. The results of the measurements are recorded in Table V in terms of the final temperature elevation and of the linear thermal resistance for each size of wire.

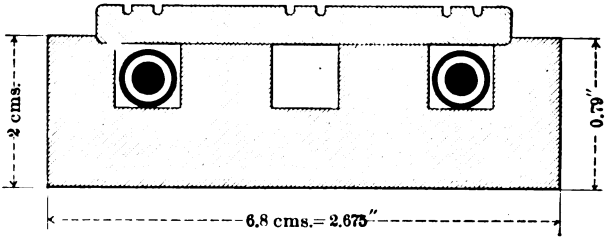

FIG. 5—Cross-section of wooden moulding

It is to be observed that the temperature elevations of these wires, whose dimensions were substantially the same as those appearing in Table I for the lengths tested in water, are more than ten times greater than those for the corresponding steady current strengths in Table III.

The linear thermal resistance of the rubber, as above deduced, is deducted in Table V from the mean linear thermal resistance of each moulded wire. The balance is the inferred linear thermal resistance in series of dry braid, air, wood and external air. This extra linear thermal resistance steadily diminished from 466.6 thermal-ohms in one linear centimetre (183.5 thermal-ohm-inches) with No. 16 wire, to 343.9 thermal-ohm-cm. (135.3 thermal-ohm-inches) with No. 8 wire. This reduction in linear thermal resistance may be accounted for by the reduction in the thickness of the air-space between braid and wooden-moulding walls, as the size of the wire was increased. With these particular sizes of wire, composition of "rubber," size and quality of moulding, the linear thermal resistance of the entire series was about ten times as great as that of the rubber alone, and consequently for a given linear thermal current I, or linear $I^2 R$ heat loss in the wire, the $\mathcal{I}\mathcal{R}$ drop, or temperature elevation θ, would be correspondingly increased about ten times. But at the higher temperature thus attained, the linear copper resistance R would be greater for a given electric current strength; so that in relation to electric current, the temperature elevation would be increased more than ten times by taking the wires out of the water and placing them dry in this wooden moulding.

TABLE V

TEMPERATURE ELEVATIONS AND THERMAL RESISTANCES OF WIRES IN MOULDING

	No. 16 A. W. G.		No. 14 A. W. G.		No. 12 A. W. G.		No. 10 A. W. G.		No. 8 A. W. G.	
	$t = 21.1°$ C.		$t = 19.1°$ C.		$t = 19.9°$ C.		$t = 19°$ C.		$t = 19°$ C.	
	θ Temp. Elev.	$\mathcal{R}$ Thermal Res.	θ Temp. Elev.	$\mathcal{R}$ Thermal Res.	θ Temp. Elev.	$\mathcal{R}$ Thermal Res.	θ Temp. Elev.	$\mathcal{R}$ Thermal Res.	θ Temp. Elev	$\mathcal{R}$ Thermal Res.
15	17.4	543.4								
20			17.6	479.9						
30	83.3	523.3	47.3	517.6	23.7	455.1	14.2	461.3		
40	173.7	487.5	93.2	498.3	51.7	507.3				
45							31.6	434.0	16.9	381.5
50			162.1	463.5	85.1	482.6				
60							61.0	427.8		
65									41.2	409.
75							106.4	417.9		
85									72.5	381.
100									105.2	363.2
	Mean	518.		490.		481.7		435.		385.
	Rubber	51.4		44.5		47.3		36.2		41.1
Braid, Air & Wood		466.6		445.5		434.4		398.8		343.9

The observed temperature elevations below 110° C. in Table V are plotted on logarithm paper in Fig. 6. The parallel straight lines there shown, fairly connecting the various series of observation points, are drawn to make an angle of 66° 25′ or the anti-tangent of 2.29. It has been pointed out that over a range of 100° C. the temperature elevation θ, above $t = 18°$ C., increases theoretically as $I^{2.289}$; whereas over a range of 50° C., as in Fig. 4, the temperature elevation θ increases as $I^{2.2}$. While the agreement between theory and observation is not so good

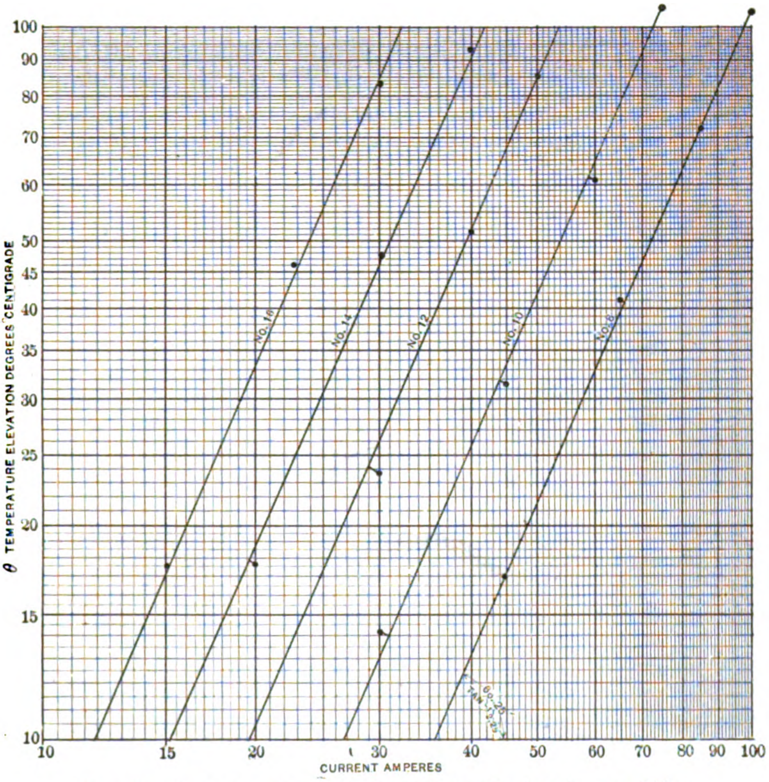

FIG. 6—Final temperature elevations of wires in moulding

in Fig. 6, as in Fig. 4, yet it may be regarded as practically satisfactory. By comparing Figs. 4 and 6, it is evident that these braided wires would carry with a given final temperature elevation some three times more current in water than in this moulding. With the braiding removed, they would carry in water nearly 3.3 times more current than when braided and in this dry wooden moulding, with the same temperature elevation. In all cases of wires cooled entirely by thermal conduction, the electric current strength I amperes which will produce a given final temperature elevation θ, above a given initial temperature t° C., must by formulas (11) and (12), vary as $1/\sqrt{\mathcal{R}}$, or inversely as the square root of the linear thermal resistance, assuming that the thermal resistivities in the series are substantially constant throughout their working range of temperature. Thus in Table V, the mean linear thermal resistance $\mathcal{R}$ of the rubber covering alone is shown to be 47.3 thermal-ohm-cms. (18.7 thermal-ohm-inches) for No. 12 wire, which would be the total linear thermal resistance of this size of wire in running water, unbraided. But in moulding, the mean linear thermal resistance of this braided wire increased to 481.7 thermal-ohm-cm. (190 thermal-ohm-inches). The ratio of increase in linear thermal resistance in the two cases would be $\frac{481.7}{47.3} = 10.2$ and the steady electric current strength which

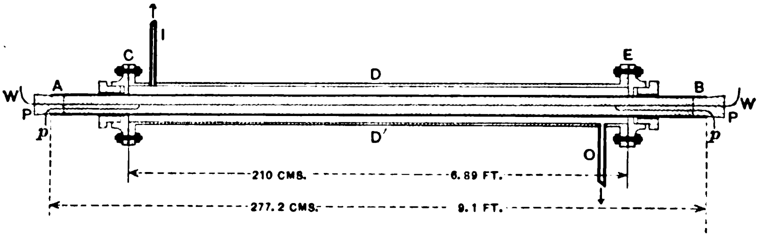

FIG. 7—Longitudinal section of water-jacketed pipe containing a test wire packed in sand, soil, or gravel

the wire could carry with an assigned temperature elevation θ° C., would be changed in the proportion $\frac{1}{\sqrt{10.2}} = \frac{1}{3.2}$ times; *i.e.*, 3.2 times more current in the water than in the moulding.

Measurements with Bare Wires Surrounded by Sand, Soil or Gravel. The heating of underground wires and cables depends, as is already known, upon the depth below the surface at which the wires are laid, and upon the thermal resistivity of the soil; as well as upon the dimensions of the wires and the currents they carry.[8] The measurement of the thermal resistivity of

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“ The Carrying Capacity of Electric Cables, Submerged, Buried or Suspended in Air,” by A. E. Kennelly. Minutes of the Ninth Annual Meeting, Association of Edison Illuminating Companies, 1893, p. 79. “ Die Berechnung Elektrischer Leitungsnetze,” Herzog-Feldmann, Vol. II, p. 130.

the soil presents some difficulty. A series of observations was made on the thermal resistivity of several varieties of sand, gravel and plaster of Paris.

For the above purpose an iron pipe *A B*, Fig. 7, 277.2 cm. (9.1 ft.) long and 8.92 cm. (3.5 in.) in external diameter, was provided with a water-jacket external cast-iron pipe *C D E*, 210 cm. (6.89 ft.) long, and 15.24 cm. (6 in.) inside diameter, as indicated in Fig. 8. A steady stream of tap water was allowed to flow through the water-jacket during each test, the water entering at the inlet *I* and issuing at the outlet *O*. The internal diameter of the pipe *A B* was measured both by calipers, and by finding the mass of water held by the pipe between the wooden end-plugs *P P*. This mean internal diameter was 7.77 cm. (3.06 in.).

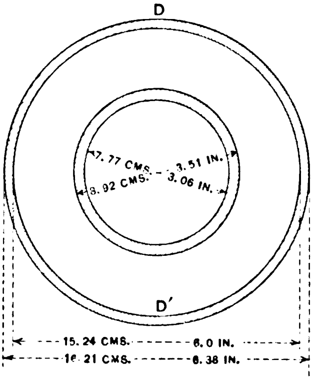

FIG. 8—Enlarged cross-section of water-jacketed pipe through *DD′* Fig.7.

The copper wire *W W* under test was held at or near the axis of the tube, and smaller pressure wires *p p* were soldered to it at points 2 metres apart (78.74 in.). The mean diameter of the wire was 0.3256 cm. (0.1282 in. or No. 8 A.W.G.). Other sizes of wire were also used.

The first substance tested was a yellow sand, of moderately fine grain, obtained from a pit in a field near the Pierce Hall laboratory and may be taken as a fair sample of sandy soil. This sand was carefully dried and packed, while still warm, into the pipe *A B*, Fig. 7, around the bare wire *W W*. A steady current of water was then allowed to flow through the water-jacket for some hours, so as to bring the temperature of the apparatus substantially to 16° C., the temperature of the tap water. A strong current was then passed through the wire *W W* with the connections of Fig. 1, and steadily maintained until the resistance of this wire, between pressure taps, showed that the final temperature had been very nearly attained. Observations of resistance were obtained at frequent intervals. Table VI gives a particular series of observations obtained with a current of 128.2 amperes kept steadily flowing through the test-wire, the initial resistance balance being secured with 15 amperes. Column I gives the clock time of each observation, column II the elapsed time from the closing of the circuit, column III the balancing resistance *r*, Fig. 1, column IV the side to which that resistance was added, columns V and VI show the respective resistances of the two galvanometer circuits, column VII gives the resistance of the 2 metres of test wire. column VIII gives the inferred temperature of the test wire, and the last column, the inferred rise of temperature.

TABLE VI.

OBSERVATIONS WITH 128.2 AMPERES PASSING THROUGH COPPER WIRE OF DIAM. 3.26 MM., IN DRY SAND, WATER-JACKET MAINTAINED AT 16° C.

I Time h.	 m.	 s.	II Time from start seconds	III Res. *r* B. A. U.	IV added to	V Resistance C side B. A. U.	VI D side B. A. U.	VII Res. of test wire Int. microhms	VIII Temp. of test wire $t+\theta$° C.	IX Temp. rise of test wire θ° C.
11	30	00	0	30	grid D	850	985	4141	16.	0.°
	30	15	15	0	—	"	955	4271	24.	8.
	31	00	60	50	wire C	900	"	4522	39.4	23.4
	31	15	75	70	"	920	"	4623	45.6	29.6
	31	55	115	90	"	940	"	4723	51.7	35.7
	34	15	255	130	"	980	"	4924	64.1	48.1
	35	35	335	144	"	994	"	4995	68.4	52.4
	37	00	420	153	"	1003	"	5040	71.2	55.2
	38	40	520	160	"	1010	"	5076	73.4	57.4
	43	00	780	174	"	1024	"	5146	77.7	61.7
	46	00	960	183	"	1033	"	5191	80.4	64.4
	51	40	1360	192	"	1042	"	5236	83.2	67.2
	54	00	1440	195	"	1045	"	5251	84.1	68.1
12	01	30	1890	204	"	1054	"	5296	86.9	70.9
	5	30	2130	207	"	1057	"	5312	87.9	71.9
	12	12	2532	210	"	1060	"	5327	88.8	72.8
	22	30	3150	213	"	1063	"	5336	89.4	73.4
	27	00	3420	215	"	1065	"	5351	90.3	74.3
	36	00	3960	218	"	1068	"	5366	91.2	75.2
	46	00	4560	220	"	1070	"	5377	91.8	75.8
13	27	00	7020	229	"	1079	"	5422	94.6	78.6
	36	00	7560	229	"	1079	"	5422	94.6	78.6
	50	00	8400	229	"	1079	"	5422	94.6	78.6

The resistance of the standard German-silver grid *D*, Fig. 1, in the above series of measurements was 4,799 int. microhms.

Fig. 9 shows at *A* the graph of the observations in the above table. The curves *B*, *C* and *D* are the corresponding graphs of similar series of measurements with 100, 77.2 and 50 amperes respectively. These four curves show the rise of temperature in the wire during the first 7,000 seconds of steady electric current flow. About half of the final temperature elevation was reached by the wire in 150 seconds. The initial rate of temperature elevation with 128.2 amperes was about 0.5° C. per

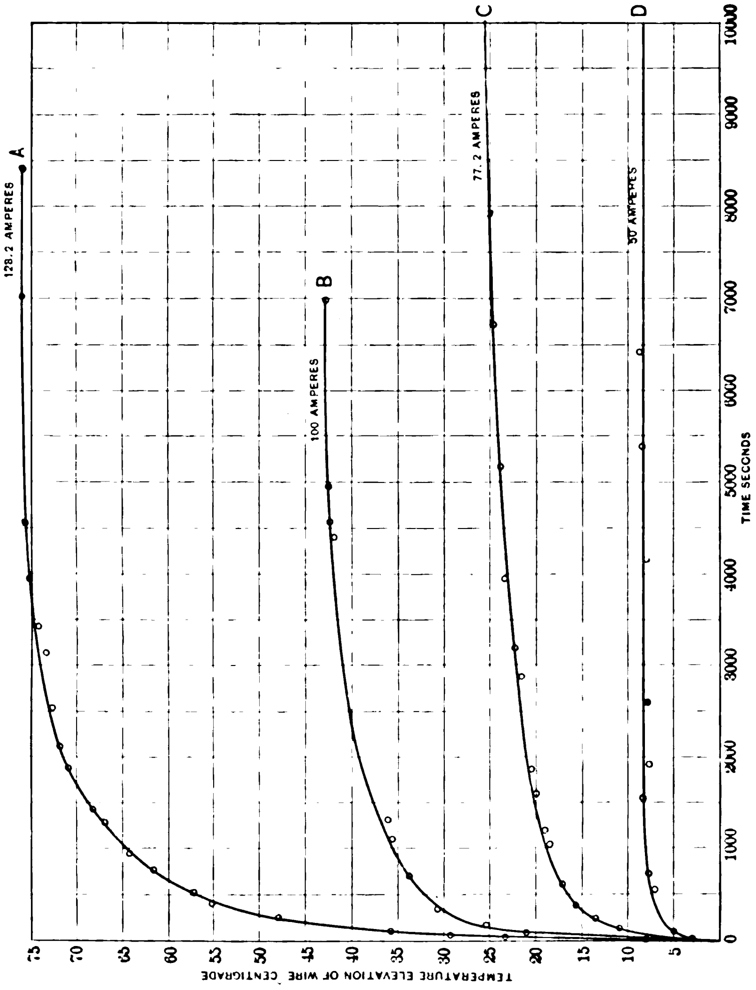

Fig. 9—Heating of wire in sand and pipe.

second. After 100 seconds this rate fell to 0.1° C. per second and after 1000 seconds to 0.01° C. per second.

In Fig. 10, the curves indicate the temperature elevation of another copper wire No. 10 A. W. G. (diam. 0.256 cm. or 0.1008 in.)

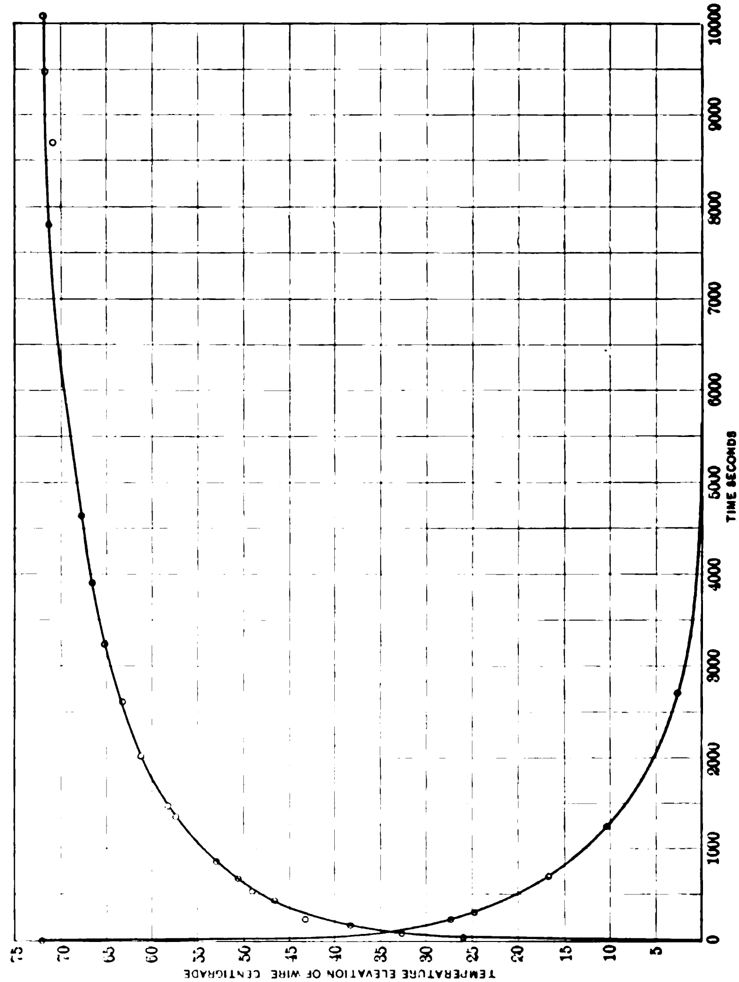

FIG. 10—Heating and cooling curves, of No. 10 A.W.G. bare copper wire in dry white sand. 90 amperes.

in relation to time, after applying a steady current of 90 amperes, and also after interrupting the current. In the practically steady state, with a temperature of 6° C. in the water circulating through the water-jacket, and a temperature in the wire of 78.1° C. or 72.1° C. temperature elevation, the linear thermal current was 0.3354 watts per cm. (0.852 watts per inch) and the linear thermal resistance 215 thermal-ohm-cm. (84.6 thermal-ohm-inches). By the use of formula (4), taking d = 0.256 cm. and D = 7.77 cm., the thermal resistivity of the sand was 395.9 thermal-ohm-cm.

The curves of heating and cooling for a No. 17 A.W.G. copper

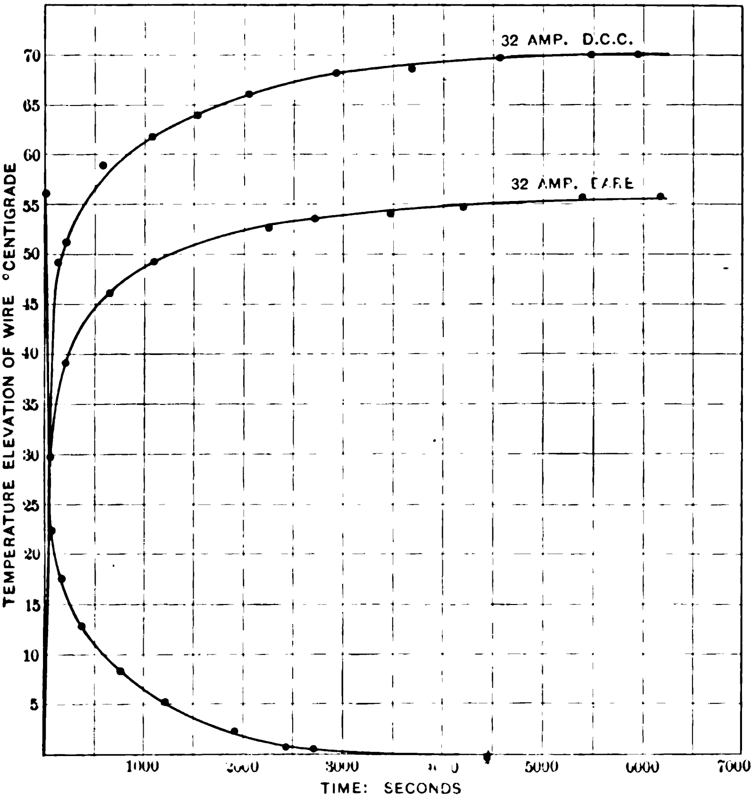

FIG. 11—Curves showing the heating and cooling of No. 17 A.W.G. wire double-cotton covered and bare in fine quartz sand.

wire of diameter 0.1132 cm. (0.0445 in.) double-cotton-covered to 0.1346 cm. (0.053 in.) are given in Fig. 11. The heating current in each case was held at 32 amperes. The upper curve shows the rise of temperature elevation with the wire when cotton-covered and packed in fine dry white quartz sand. The lower curve gives the corresponding temperature elevation rise after the cotton covering had been removed from the wire, and the same replaced in the pipe with the same quartz packing. The descending curve gives the cooling in the latter condition. It will be observed that both in this figure and in Fig. 10, the cooling occurs more rapidly than the heating. That is, the cooling falls to 1° C. remaining temperature elevation in about half the time that the heating process requires to attain within 1° C. of the final temperature elevation.

The thermal resistivity of the dry cotton covering on the wire appears to have been 2373 thermal-ohm-cm., the highest resistivity of any of the substances tested.

The following table gives a collection of all the measurements of thermal resistivity made with the water-jacketed pipe.

Column I in the above table describes the material employed in packing the pipe; or the nature of the thermal insulator tested. The size of the square aperture in a wire screen sieve through which the bulk of the material would pass is also given. Column II states the condition of the material as to dryness. The additions of liquid referred to are in percentages of volume. Column V gives the strength of the continuous current used in each test, and column VI, the temperature elevation θ° C., thereby finally produced, with water usually at or near 5° C. circulating in the cooling jacket. The diameter of the bare copper wire used is given in column VII.

Column VIII shows the computed thermal resistivity σ, of the material, as deduced from the temperature elevation θ, and the linear thermal current in watts per cm. Column IX gives the thermal resistivity σ', as deduced from the linear thermal current when expressed in lesser calories, or water gram-deg. cent. per linear cm. The thermal resistivity of a substance expressed in calorie measure is 4.186 times greater than when expressed in watt measure, 1 gram-calorie per second being taken as 4.186 watts. Column X contains the thermal conductivity of the substances in watt measure, or the reciprocal of σ in column VIII. Column XI contains the thermal conductivity of the substances in calorie measure; or the reciprocal of σ' in column IX.

It will be observed that the thermal resistivity varied between 161.4 thermal-ohm-cm. for quartz sand with 20% water and 761.7 thermal-ohm-cm. for dry powdered plaster of Paris. The dry cotton covering of the wire whose heating is shown in Fig. 11, had, however, a resistivity of 2373 thermal-ohm-cm.,

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which corresponds to a thermal conductivity of 4.214×10^{-4} thermal mhos-per-cm. in watt measure, or 1.007×10^{-4} thermal-mhos-per-cm. in gram-calorie measure. This agrees with the value for cotton wool given by Peclet.[9]

Fig. 12 shows the relation of the observations with the temperature elevation of wires in the water-jacketed pipe to the steady current strength when plotted on logarithm paper. The parallel straight lines are drawn to make an angle of 66° 30′ or the anti-tangent of 2.3, to cover a range of 100° C. temperature elevation from an initial temperature of 6° C., in accordance with formula (13) adapted to 100° C. instead of 50° C. The agreement between the observation points and these straight lines of average exponent 2.3 is fairly satisfactory from an engineering standpoint.

The following conclusions may be drawn from the observations here reported:

(1) The fundamental formula for the direct-current final heating of a wire that cools by conduction is (12)

$$\frac{\theta}{1+a\,\theta} = K\,I^2$$

where K is a constant for the wire determined by the total linear thermal resistance. This formula applies to concealed wires, *i.e.*, to insulated wires in water, in the ground, or in wooden moulding.

(2) The thermal resistivities of the various substances tested with different temperature elevations, including rubber composition, braiding, moulding, and various soils, may, for practical purposes, be regarded as constant, *i.e.*, not appreciably affected by temperatures up to 100° C.

(3) Wet braiding on a No. 14 rubber-covered wire added a linear thermal resistance of 8.7 thermal-ohm-cm. (2.46 thermal-ohm-inches) and raised the final temperature of the wire immersed in water by about 2° C. with 50 amperes.

(4) The linear thermal resistance of the rubber-covered wires in dry wooden moulding was about 10 times greater than when immersed in water, thus increasing their temperature elevations more than 10 times with a given current, or reducing their current-carrying capacity more than 3 times for a given temperature elevation.

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[9] "C. G. S. System of Units," by Everett—Heat Conduction of Woolly Substances, p. 128. London, 1891.

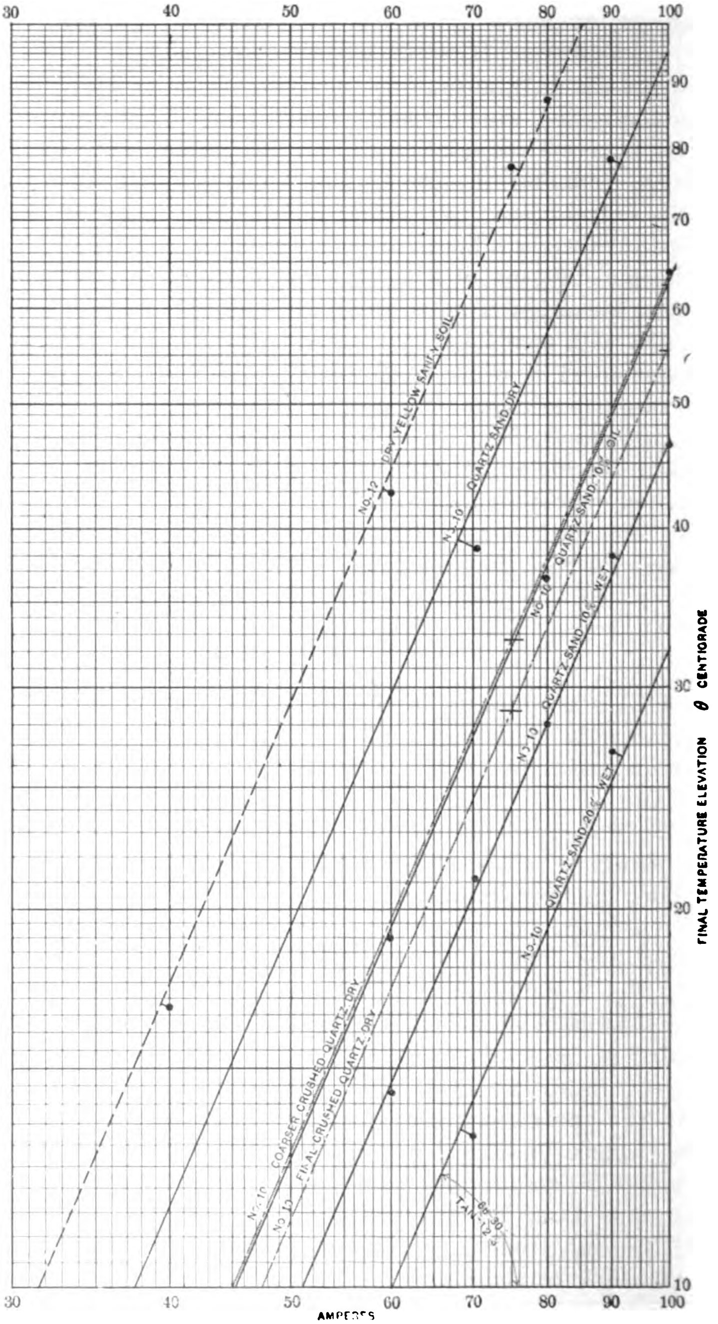

Fig. 12—Final temperature elevations of bare wires in water-jacketed pipe, with different packings.

(5) When plotted on logarithm paper, the final temperature elevation of a wire in relation to steady current strength is nearly a straight line of inclination $\tan^{-1} 2.2$ (Fig. 4) for temperature elevations not exceeding 50° C., and not far from a straight line of inclination $\tan^{-1} 2.3$ for temperature elevations not exceeding 100° C. (Figs. 6 and 12).

(6) A No. 12 A.W.G. copper wire, rubber-covered and immersed in water substantially attained its final temperature elevation in 300 seconds, or 5 minutes, after applying a steady current. The same wire in dry wooden moulding took 1800 seconds, or 30 minutes, and the same wire bared, but packed in sand, within a water-jacketed pipe of 7.77 cm. (3.06 in.) internal diameter, took about 7800 seconds, or 130 minutes, to reach a similar approximation to final temperature elevation.

(7) The wires in the water-jacketed pipe cooled more quickly than they heated.

(8) Changing the size of the wire in the water-jacketed pipe from No. 8 (0.326 cm.) to No. 12 (0.205 cm.) did not appreciably affect the thermal resistivity of sandy soil as measured with these wires (351 thermal-ohm-cm.) Similarly, changing the size from No. 10 (0.256 cm.) to No. 17 (0.113 cm.) did not appreciably affect the thermal resistivity of dry quartz sand as measured by those wires (400 thermal-ohm-cm.).

(9) The thermal resistivity of the sandy soils tested was greatest when those soils were dry and diminished with the addition of water or oil to them.

(10) The thermal resistivity of a sample of crushed quartz was greater with the material in a coarse condition. Crushing the particles of quartz to about half their previous linear dimensions reduced the thermal resistivity of the material about 10%.

(11) The lowest thermal resistivity observed was that of quartz sand with 20% of water added by volume—161.4 thermal-ohm-cms. The highest was that of the white dry double cotton covering of a wire—2373 thermal-ohm-cm., both in watt measure.

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25, 1907.

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INTERACTION OF SYNCHRONOUS MACHINES

A Graphical Solution by Means of a New Circle Diagram

BY MORGAN BROOKS

When two synchronous machines are in operation as generator and motor, the amount of power demanded of the motor causes it to assume a definite phase relation to the generator, somewhat dependent also upon their relative excitation and upon the impedance of the circuit including the two machines. When such machines are operating in parallel there is theoretically no power to be transferred, but this ideal condition can only exist when the excitation and phase relation of the machines are identical; if these differ, even by a small amount, transfer of power must take place between generator and motor. The power required by the motor causes a certain vector difference; conversely, the presence of a vector difference points to a definite transfer of power from one machine to the other.

The object of this paper is to present a new circle diagram showing the physical relation of the quantities and conditions involved, to derive and interpret the fundamental equations, and to develop simple loci for solving graphically or numerically the problems of synchronous operation. While based upon strict mathematical analysis, it is hoped that the simplified diagram here shown will be found so direct and rational as to make the analytical method more easily understood and generally serviceable.

The elementary theory of synchronous alternating machines assumes that successive instantaneous values of electromotive force and current follow one another in a manner strictly harmonic. Oscillograph records from normal alternators so closely approximate sine-wave forms as to justify the theory. Irregularities, if considerable, indicate an unsatisfactory machine, one not amenable to simple calculations; but if slight they may usually be neglected, or the irregular wave be replaced for the purposes of calculation, where circuits have small reactance, by what is known as its "equivalent sine wave," having the same effective value.

A true sine wave is determined by the projection upon a fixed axis, usually vertical, of a uniformly rotating vector, whose length gives the value and whose period is the frequency of the harmonic quantity represented. Such a rotating vector could not be seen by the eye, and in order to make use of it an imaginary snap-shot is taken of it, giving the position of the vector at a certain instant. A picture or diagram of this sort showing the relation of two or more machines as they exist at a given instant, illustrates the interaction of synchronous machines, and may even allow us to make satisfactory calculations as to operating conditions.

In Fig. 1 let the line *O-A*, or briefly *A*, represent the electromotive force (preferably the measured or effective rather than the maximum value) of a single-phase alternator, and let *O-B* or briefly *B*, represent the value and relative position of the electromotive force of another alternator. If the machines so represented are running separately, their vectors may assume any angular relation and need not be of the same length, since the machines may not be equally excited or driven at precisely the same speed. Such a diagram would be understood to mean merely that the machines are adapted to operate together, and are running at approximately the same speed and excitation. For convenience, our snap-shot will always be taken when machine vector *A* is vertical, so that the relative difference of vector position is confined to *B*. If the two machines represented in Fig. 1 are about to be connected in parallel, it is understood that the vectors should be found nearly coincident before the paralleling switch is closed, after which the machines should continue to run with vectors coincident, or nearly so. If hunting should exist, its vector representation would be in the oscillating position of the two vectors, now one ahead slightly, now the other, their possible separation indicating the greatest amplitude of the hunting action. The position of *B* with reference to *A* in Fig. 1 might represent either an extreme position of hunting, or a limiting position for switching into parallel. If two machines, equally excited, were thrown into parallel when their vectors were coincident, connection being understood both at *O* and at *A-B*, no current would flow in the local circuit; but if the machine vectors were

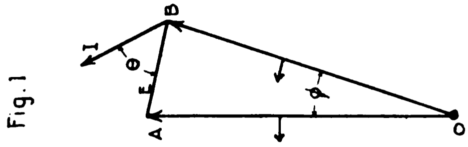

FIG. 1—Vector diagram

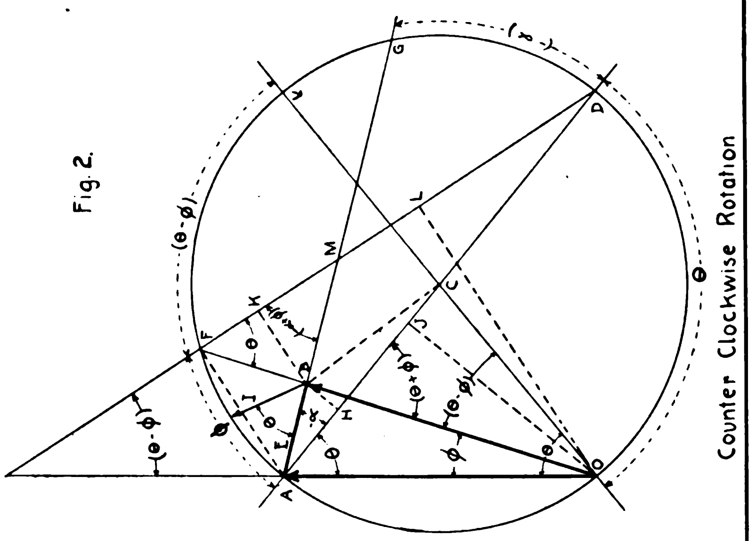

FIG. 2—Circle diagram

a little out of exact coincidence, as *A* and *B* in Fig. 1, then a current would flow between the machines, owing to the vector-difference voltage, *A-B*, existing in the local circuit, since it is possible to take *A-B* to represent the vector difference of the voltage *O-A* of machine *A*, and voltage *O-B* of machine *B*. *A-B* represents the only electromotive force acting and we may use *E* in place of *A-B*. The current, *I*, that *E* will drive through the circuit, depends upon the impedance, *Z*, of the local circuit, which includes both machines as well as the line connecting them. Since the impedance of a synchronous machine is of such a value as to allow full-load current to flow on applying about one-third normal voltage, when two machines are coupled directly together in one circuit about two-thirds of the normal voltage of one machine is required to produce full-load current. When *E*, or *A-B*, is equal to two-thirds of *O-A*, which occurs when angle $A\text{-}O\text{-}B = 39°$, approximately full-load current will flow. This " circulating current " acts to diminish the angle between the vectors; that is, to bring the machines more nearly into phase, and normally the two machines operating in parallel will be maintained closely in phase, since much less than full-load current is required to compel proper phase relation. It is to be noted, however, that there is no compelling action whatever when phase coincidence exists with equal excitation. The current prevents a separation but does not hold the machines firmly together as often supposed.

Assuming counter-clockwise or trigonometrical rotation of our machine vectors, *A* and *B*, the machine whose position is in advance; that is, *A* in Fig. 1, is a generator, and is retarded by reason of giving out power; while the machine whose position is behind; that is, *B* in Fig. 1, is a motor, and is accelerated by the power received. The tendency is to bring the machines into step. If the action should be strong enough to drive *B* ahead of *A*, the circulation of current is reversed; *B* would be retarded by becoming a generator, while *A* would be accelerated as a motor. It is easy to see that hunting might occur from excessive action and reaction. Synchronous machines operating in parallel are then held together by a sort of elastic band, not under tension when the machines are in step, but preventing them from pulling far out of step by a rapidly increasing force, a force that may prove unnecessarily strong, causing a hunting action.

The value of the synchronizing force under working conditions may be calculated, as will be shown. When two machines are operating together under light load, if one loses its driving power it will fall behind its normal parallel vector position only just far enough to enable it to receive current to maintain it in step. No noticeable change in running occurs. It is often supposed that when a generator becomes a motor it falls behind 180 electrical degrees, while in fact it falls behind a very small angle, perhaps 10°. When two machines are transmitting power in the relation of generator and motor, the current flowing between the machines is no longer called circulating current. The motor takes a vector position sufficiently behind the generator to produce the vector difference, E, required to drive the current corresponding to the power demanded of the motor. In parallel operation the machines are usually contiguous, and the current which may "circulate" has in general only the impedance of the machines to limit it; while in generator-motor operation a transmission line with transformers and potential regulators is commonly included, producing a condition as to impedance quite different from parallel connection.

A number of synchronous machines may be operated together, some as generators and some as motors, and the machines may vary greatly in size. To simplify the problem two identical single-phase machines, A acting as generator and B acting as motor, will be considered as connected in a single circuit, so that any current generated in A must pass through the armature of B. The problem commonly provides that the terminal potential of the generator shall be maintained constant, while the excitation of the motor shall be under control. Constant frequency or speed is assumed. The line is assumed to have its resistance, r, and its reactance, x, [$= 2 \pi f L$ neglecting capacity effects] constant, and the motor resistance and reactance are also assumed as constant. To include the capacity reactance of a transmission line would change the assumption that all the current generated must pass through the motor, since the capacity of the line acts as an alternative path. The capacity or line-charging current being nearly wattless, the power determinations of the problem are not greatly affected by their omission under load conditions of operation. A correction may be made to obtain the total current required of the generator. The assumption of constant impedance for the synchronous motor, while not precisely true, is akin to the assumption of constant friction loss in engine operation. Except for abnormal conditions, it is believed that no great error is thus introduced. This gives the ratio of R to Z [$R/Z = \cos \theta$], or the power-factor of the circuit as a known constant, and enables a simple diagram to be plotted.

The regular equations of synchronous operation will now be developed by means of Fig. 2, which differs from Fig. 1 only in the drawing of a circle, whose diameter is $A/\cos\theta$, so centered as to make A a chord, in the extension of vectors A and E, to intersect the reference circle at F and G, and in projection of the electromotive force vectors, A, B and E, upon the circle's diameter, $A\,D$, and upon the chord $F\,D$, the utility of which projections will presently appear.

NOTATION

A, short for $O\,A$, a vector representing generator terminal voltage, assumed to be kept constant. Vertical position chosen for convenience.

B, short for $O\,B$, a vector representing the induced motor voltage, variable both as to length and direction. Position shown in Fig. 2 indicates any position whatever in its relation to A.

E, or $A\,B$, a vector representing the vector difference of A and B, or the net voltage acting in the circuit which includes the motor.

I, the current produced by E. $I = E/Z$.

R, the resistance of the motor and circuit.

X, $[= 2\,\pi\,f\,L]$ the reactance of the motor and circuit.

$Z = \sqrt{R^2+X^2}$ $[R+j\,X]$, the impedance of the motor and circuit.

θ, the angle between E and I. It is a constant determined by the condition.

$\cos\theta = R/Z$, the power-factor of the circuit, often confused with $\cos a$, below.

θ appears in Fig. 2 as the angle made by the lines $A\,C$ and $O\,C$ with vector A; the reference circle is determined by having their intersection C as its center.

ϕ, the angle between A and B, a variable, assumed positive when B lags behind A as shown, the usual condition of operation, when B is a motor.

$\theta + \phi$, the angle between B and $A\,C$, since θ is the angle between $A\,C$ and A, and ϕ that between A and B.

$\theta - \phi$, the angle between A and the chord $F\,D$, which lags behind $A\,C\,D$ by the angle ϕ.

a, the angle between A and I, a variable, considered positive when I lags behind A due to B being under-excited.

$\cos a$, the generator power-factor, sometimes confused with $\cos\theta$ above.

a, appears on the reference diagram as the angle $B\,A\,C$, or the angle between $A\,C$ and E. A lags $\theta°$ behind $A\,C$ by construction, I lags $\theta°$ behind E by definition, hence it is seen that angle $B\,A\,C$ is also angle of I to A. Normal excitation reduces this angle to O, and $\cos a = 1$.

$a - \phi$, the angle between B and I, since B lags $\phi°$ behind A, This angle is usually negative, as a is normally small; that is, I usually leads B.

$a - \phi$ appears on the reference diagram as $A\,M\,F$, or angle between E and chord $F\,D$.

$\cos(a - \phi) = \cos(\phi - a)$ might be called the motor power-factor.

These angles are conveniently measured by half the intercepted arcs, as indicated in the diagram, Fig. 2.

P', the power output of the generator $= A\,I\cos a$.
P'', the power intake of the motor $= B\,I\cos(a - \phi)$.

The diagrams are calculated for values as follows:

$A = 1000$ volts, and
$R = 1$ ohm.

Where $\theta = 45°$, $X = 1$ ohm also, and $Z = 1.41$ ohm.
" $\theta = 60°$, $X = 1.73$ ohm, and $Z = 2$ ohms.
" $\theta = 75°$, $X = 3.73$ ohms, and $Z = 3.86$ ohms.

With the above the power figures in Figs. 4b and 6 are in kilowatts.

From the projections of A, B and E on diameter $A\,D$, Fig. 2. it is evident that $A\,J - H\,J = A\,H$, or as

$$A\cos\theta - B\cos(\theta + \phi) = E\cos a \qquad (1)$$

Multiplying by A/Z,

$$\frac{A^2\cos\theta - A\,B\cos(\theta + \phi)}{Z} = A\,\frac{E}{Z}\cos a = A\,I\cos\alpha = P' \qquad (2)$$

the generator output.

From the projections of A. B and E upon the chord $F\,D$, it is evident that

$$F\,L - K\,L = F\,K, \text{ or}$$

$$A\cos(\theta - \phi) - B\cos\theta = E\cos(a - \phi). \qquad (3)$$

Multiplying by B/Z,

$$\frac{A\ B\cos(\theta-\phi)-B^2\cos\theta}{Z}=B\frac{E}{Z}\cos(a-\phi)$$

$$=B\ I\cos(a-\phi)=P'' \qquad (4)$$

the motor intake.

The difference between generator output and motor intake is lost in heat, as with direct-current machines; this is shown in equations 2 and 4:

$$P'-P''=\frac{A^2\cos\theta+B^2\cos\theta-2\ A\ B\cos\theta\cos\phi}{Z}$$

$$=\frac{R}{Z^2}[A^2+B^2-2\ A\ B\cos\phi]=\frac{R\ E^2}{Z^2}=R\ I^2 \qquad (5)$$

Equations 2, 4 and 5 above, are the well-known fundamental equations of synchronous machine operation, and while derived from the relation of two machines operating as generator and motor, they apply to two machines in parallel operation, provided the current be now understood as circulating current only.*

Power Output.

1. Interpretation of equation 2 above.

$$P'=A\frac{E}{Z}\cos a$$

or,

$$E\cos a=\frac{P'Z}{A},$$

a constant for any given value of generator output, P'. Hence for constant P', $E\cos a$, the projection of E on diameter $A\ D$, is constant or the locus of B lies in a line perpendicular to $A\ D$, such as $N\ Q$, Fig. 3. The equation is the regular polar equation of a straight line. The power output of generator P' is directly proportional to the length of the projection on $A\ C$, and hence measured thereby. Parallel lines drawn at equal distances apart, serve as a chart for reading the value of P' when position of B is known.

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*Compare Franklin & Williamson, Alternating Currents, page 189. Second Edition.

With $P' = O$, the locus becomes the tangent to the reference circle at A. For positive values of P'; that is, generator action, the parallels are to the right of this tangent; for negative values of P''; that is, for motor action, reversing the ordinary conditions of the problem, parallels may be drawn to the left of the tangent, shown in dotted lines in Fig. 3. For such positions of B making A a motor, it is evident that machine B must become the generator, as will be demonstrated under 2. Mathematically there is no limit to the possible values of P', either positive or negative. Operating values are limited by the possible excitation of B, and normal operating values of P' would not ordinarily exceed corresponding values of P'', the motor intake, by more than 25%, the condition for 80% efficiency. Excessive values of P' will exist momentarily in synchronizing two machines if the switch be closed at an unfavorable vector position.

Power Intake.

2. Interpretation of equation 4.

$$P'' = \frac{A\ B \cos(\theta - \phi) - B^2 \cos\theta}{Z}$$

Transposing,

$$B^2 - B \frac{A}{\cos\theta} \cos(\theta - \phi) = -\frac{P'' Z}{\cos\theta} \qquad (6)$$

a constant for given intake, P''. This equation is the polar equation of a circle, as may readily be seen from Fig. 2 as follows:

Substituting for $A/\cos\theta$ its value, $2\,(O\,C)$, adding $(O\,C)^2$ to both members, and writing $(O\,B)$ for B,

$$(O\,C)^2 + (O\,B)^2 - 2\,(O\,C)\,(O\,B) \cos(\theta - \phi) = (O\,C)^2 - \frac{P'' Z}{\cos\theta}$$

The first member evidently gives the remaining side of the triangle $O\,C\,B$, and we have

$$(C\,B)^2 = (O\,C)^2 \frac{P'' Z}{\cos\theta} \text{ or } (C\,B) = \sqrt{(O\,C)^3 - \frac{P'' Z}{\cos\theta}} \qquad (7)$$

The second member is constant for constant load on motor, hence for such load the locus of *B* lies in a circle centered at *C*, and of radius determined by the radical.

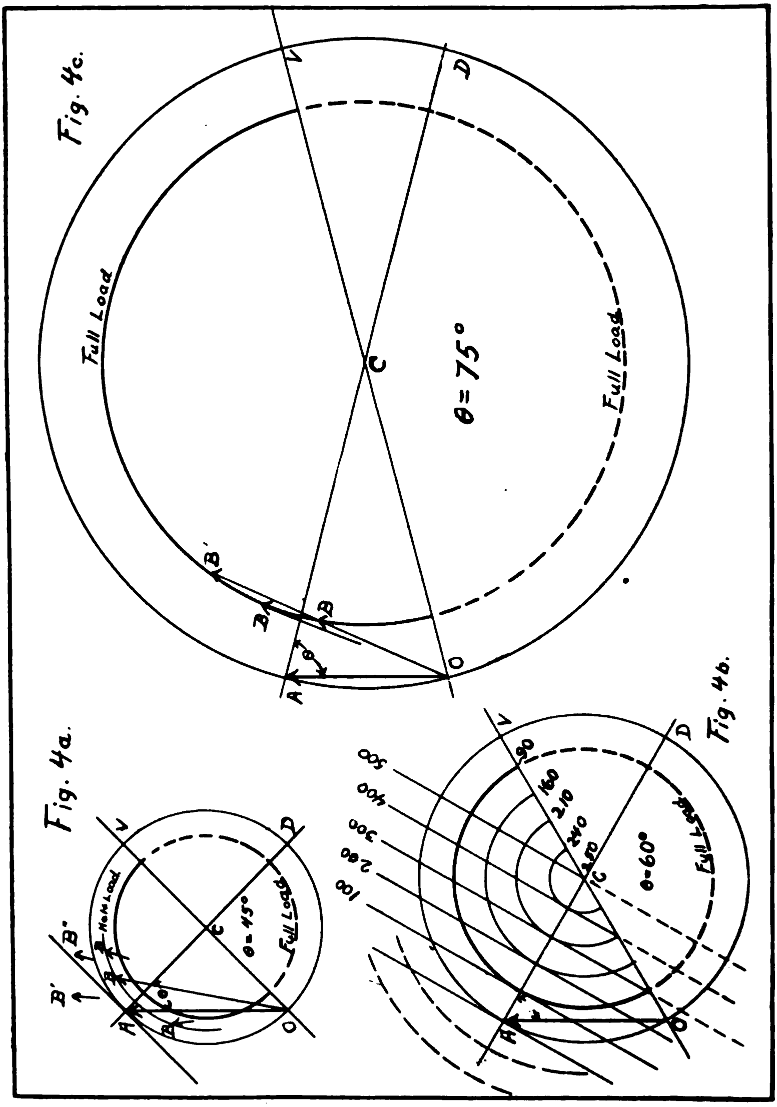

FIG. 4a—Locus of *B* for constant motor intake. FIG. 4b Same for $\theta = 60°$. FIG. 4c—Same for $\theta = 75°$

For $P'' = O$, this reduces to $(O\,C)$, meaning that *B* lies in the circumference of the reference circle, which has *C* for its center, and *O C* for radius, when the intake of the motor is zero.

This is evident since I lags 90° behind B for any point in the circumference. There may be a large current, and the $R\ I^2$ losses are supplied by the generated power P'.

Negative values of P'', meaning that machine B has its function reversed and acts as a generator, bring B necessarily outside the reference circle, as at B' and B'', Fig. 4. There is no mathematical limit for such external values. If the position of B is also to the left of the tangent, ST, as at B', the function of machine A is also reversed, being a motor, while if the position lies to the right of the tangent, $S\ T$, but outside the circle, as at B'', A remains a generator, and both machines act as generators to supply the large $R\ I^2$ losses of such a position.

Positive values of P''; that is, normal motor action, give loci for B within the reference circle, the value of $C\ B$ diminishing with increasing load, as can be seen from equation 7. The locus for any given load is a definite circle, whose radius is readily determined. Loci differing by equal amounts, as loci for 50, 100, 150, and 200 kilowatts, will be separated in such manner as to have equal areas in the rings included between successive loci. In equation 7 if $\frac{P''\ Z}{\cos\theta}$ exceeds the value of $O\ C^2$, the value of $C\ B$ is an imaginary quantity; that is, the motor must fall out of step when such an excessive load is applied.

$$\frac{P''\ Z}{\cos\theta} = (O\ C)^2$$

is the limiting case, the maximum load which the motor will theoretically carry. $C\ B = O$; that is, the point C is the locus for this load, which is several times full load. At this point $B = O\ C$, and $P'' = \frac{B^2\cos\theta}{Z}$. Equation 2 gives the generator power for the same point as follows:

$$P' = A\cos a\frac{E}{Z} = \frac{A\ B}{Z} = 2\ B^2\frac{\cos\theta}{Z}$$

It will be noted that this is just twice the value of P'', showing 50% efficiency, as with direct-current motors at maximum load. Loci for normal loads are circles but little smaller than the reference circle.

Efficiency.

3. Interpretation of equation 5,

$$P' - P'' = \frac{R E^2}{Z^2}$$

Dividing by P', which by equation 2 $= A \cos \alpha\, E/Z$

$$1 - \frac{P''}{P'} = \frac{E R}{Z A \cos \alpha} = \frac{E \cos \theta}{A \cos \alpha}.$$

Transposing,

$$\frac{A}{\cos \theta} \left(1 - \frac{P''}{P'}\right) = \frac{E}{\cos \alpha} \qquad (8)$$

For a given value of efficiency, P''/P', the first member becomes constant, and the equation is the polar equation of a circle. For different efficiencies, circles of different diameters are found, but all pass through the common point A, which is common to all positions of E; they are all tangent to $S\,T$ at A.

For efficiency = 1 the locus of B is reduced to the point A.

For efficiency = 0.9 the locus of B lies in a circle whose diameter is 0.1 $A/\cos \alpha$.

For efficiency = 0.8 the locus of B lies in a circle whose diameter is 0.2 $A/\cos \alpha$.

For efficiency = 0.5 the locus of B lies in a circle whose diameter is 0.5 $A/\cos \alpha$.

For efficiency = 0 the locus of B lies in a circle whose diameter is 1. $A/\cos \alpha$.

These loci are sufficient to indicate any desired efficiency. For zero efficiency the locus coincides with the reference circle, which is also the locus of zero intake of machine B. Fig. 5 shows loci for given efficiencies as marked.

Heat Loss. Equation 5, $P' - P'' = R\,I^2$, shows that the machine A not only furnishes the power P'' to machine B, but also supplies the heat losses $R\,I^2$ of the circuit. These losses should include the core losses of transformer and motor, and for better interpretation the second member might read $R\,I^2 + H$, meaning by H the core losses, which are approximately constant and independent of current. It is seen that the $R\,I^2$ losses proper, or copper losses, assuming R as constant, depend upon I^2, hence

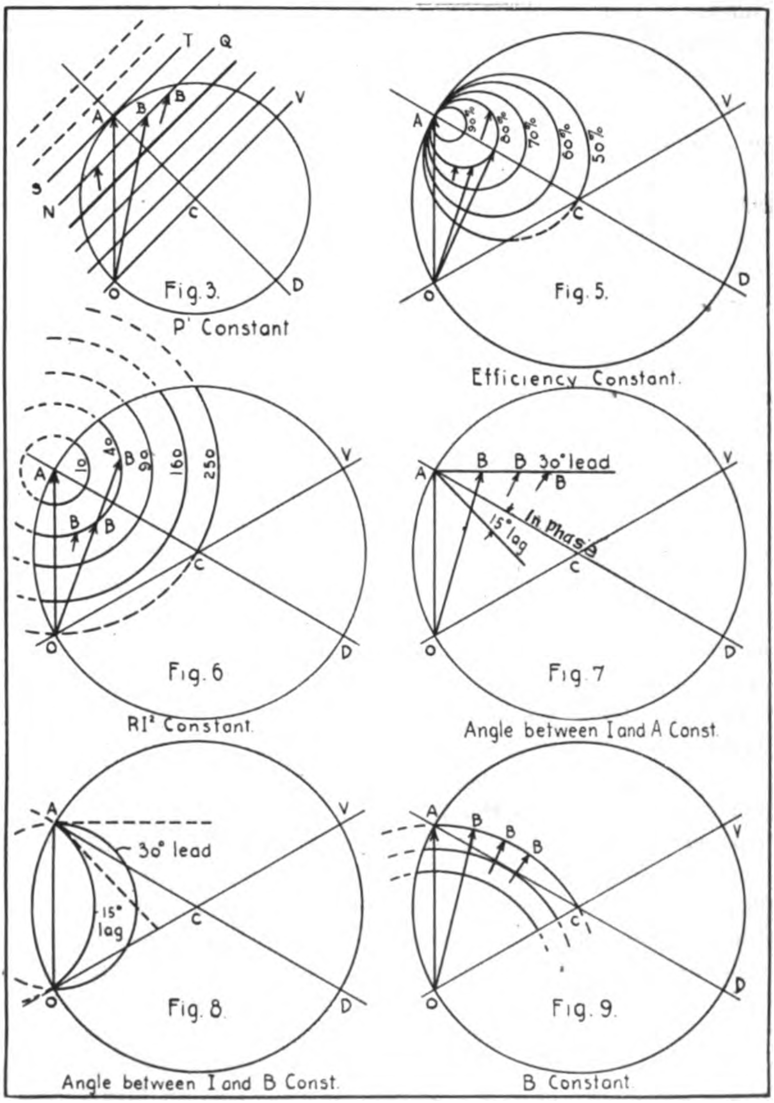

FIG. 3—Locus of B for constant generator output
FIG. 5—Locus of B for constant efficiency
FIG. 6.—Locus of B for constant I^2R loss
FIG. 7—Locus of B for given current angle referred to generator
FIG. 8—Locus of B for current referred to motor
FIG. 9—Locus of B, when of constant value.

upon I, and upon E, which produces I. For any given loss, whether or not including core losses, the locus of B will be at a constant distance from A, that is, a circle centered at A and readily determined; see Fig. 6.

Power Loci. It is easier to calculate values of P'' from considerations of efficiency, than from equation 7. What constitutes full load for a given motor is a matter of engineering judgment, commonly called "rating." For normal power transmission an average of copper losses may be taken at 10%, whence the efficiency, as here defined, is 90%. This does not include losses in the generator. In Fig. 5 the efficiency locus for 90% is shown. At the point where this efficiency circle cuts the line $A\ C$, a line marked 100, parallel to $S\ T$, marks the locus of P', while the circle marked 90 marks the locus of P''. The power ratings will be in the ratio of 100 to 90 to produce an efficiency of 90%. The 90 circle may fairly represent full load on the motor. The next parallel, marked 200, is the locus of P', and the circle touching it, marked 160, is the locus of motor intake, 160 being 80% of 200. In the same way parallels 300, 400 and 500, and the circles 210, 240 and the point 250 are determined. The maximum of P'' in every case is at the point C. The maximum intake of the motor on this basis is $250/90 = 2.8$ times the full-load rating. The current flowing is just five times that required for full load. By a different rating of the motor other ratios would be found.

Lag and Lead. Combinations of two or more sets of loci give many other interesting facts. For any given power, the locus in general has two intersections with a given efficiency circle, showing that there are two positions of B for the same efficiency of load. A point between can be found where more power is transmitted at higher efficiency. Where an efficiency circle touches a power circle is the highest efficiency for that power. All such points of tangency lie in the line $A\ C$, the locus of B to bring current in phase with A, the generator e.m.f. Here angle a is zero. With angle a positive, B lies below or to the left of the line $A\ C$, indicating that current lags behind the vector, A; with angle a negative, B lies above or to the right of $A\ C$, causing current to lead vector A. The locus for any required lag or lead is easily drawn by merely passing a line through A, making the desired angle with $A\ C$, the normal line. Such loci are shown in Fig. 7.

The loci for current in phase with B, or at any desired angle with B, are drawn almost as easily. They are arcs of circles passing through A and O, and tangent to the corresponding straight loci for same angles with respect to current and A, as shown in Fig. 8.

B Constant. Loci for given values of excitation of B are simply circles with radius centered at O, Fig. 9. If the two synchronous machines are operating as generator and motor, it is evident that the intersection of such locus of B, representing given excitation with the locus of the load, P'', of the motor will show the vector position of B for the conditions given. If the load be increased, the intersection must be with a smaller power circle representing the increased load. The machine B falls back slightly until this intersection is reached. Since in general falling behind places the motor in a region of greater power intake, the action is stable. If, however, the load is increased so much that the vector does not intersect the required load circle until it has come into line with the diameter $O\ C\ V$, running is unstable, because the slightest falling behind brings less power to the motor, and it necessarily falls out of step.

The diameter $O\ V$ appears as a definite boundary for stable running, but as armature reaction is not taken into account in the analysis, it is not to be entirely relied upon. From Fig. 4a it would appear that a demagnetizing armature reaction would bring the vector B, if equal to A, more nearly to the point C, the locus for greatest intake of power; while in Fig. 4c demagnetizing reaction would carry the vector B further away from that point. Currents that are in phase with A, meaning normal positions of B for maximum efficiency along the line $A\ C$, are demagnetizing for B. Since the action of the current is normally demagnetizing upon the motor, a satisfactory operating angle for θ is somewhat less than 60°, a condition fairly well shown in Fig. 2. If B exceeds $A/\cos\theta$, the diameter of reference circle, the machine B is incapable of operating as a motor, since B must then fall outside all possible loci of power intake.

Reactors. The use of a reactance coil increases the angle θ. For long lines, where owing to resistance θ may be small, its use is justified. For proper operation it is easy to use too powerful a regulator, as seen from Fig. 4c where $\theta = 75°$. Here it is only possible to obtain the large values of motor intake by exciting the motor greatly beyond the value of A. Hence if only moderately excited, the motor would fall out of step too easily. Effort should be made to make θ about 55° to avoid manipulation of field rheostats. Where the transmission line is short, the angle will probably exceed this, but to reduce the angle by the introduction of resistance would of course be very objectionable, as it would decrease the efficiency. It might be possible to select a machine with lower inductance than usual for such short line conditions, as for operation in parallel.

Condenser Action. The above paragraph must not be confused with the question of over-excitation to produce the so-called "condenser effect," giving a leading current in respect to A. Over-excitation makes the angle a negative; that is, it is excitation carrying vector B beyond the line $A\ C$, the normal excitation locus. It is seen that this is not a constant excitation, but depends upon the other conditions of the circuit, load, etc. With θ greater than 60°, over-excitation means as a rule, excitation of B greater than that of A; while with θ less than 60°, B may be over-excited, and yet be less excited than A. Under-excitation is less than normal, making the current lag, due to a positive angle a. It is possible to have under-excitation, and yet an excitation greater than that of the generator. This may be the case at heavy loads with a large angle θ. It may be remarked that "condenser effect" is not a true capacity action, since such effect would not tend to increase the triple-frequency component of current, as would be the case with true capacity.

Converters. Synchronous converters may be compound-wound, and so operate successfully on circuits where the angle θ is considerably more or less than 60°. For short lines, where θ is large, the converter series-winding should be cumulatively connected, to increase the excitation when loaded. This will be the proper condition for such a machine serving lighting circuits, where over-compounding is desired. For long lines powerful reactors may be required to make the use of compound-wound converters feasible. For railway service, where precision of direct-current voltage is less important, it may be satisfactory in the case of a low value of angle θ to reverse the series-winding, making it differential. Operation at least would be more satisfactory. A shunt-wound converter is often preferred, and should act well on moderately long lines. This diagram shows why there has been a spirited discussion of the relative advantages of cumulative and differential connection of the series-winding in converters, the difference in action being due to external conditions.

Synchronizing. The constants determining the diagram for showing the behavior of synchronous machines in operation, even under the abnormal condition of falling out of step, are not applicable in making a diagram to predict the initial circulating current upon connecting the same machines in parallel. If two machines are pulled out of step without opening the circuit, it is unusual for any damage to the machines to result, although they pass through all possible phase relations. Yet experience proves that it is unsafe to close a paralleling switch except at or near coincidence of phase. The reactance of an inductive circuit upon first closing the switch depends upon the coil-winding, as if it were without iron, while as soon as the core becomes synchronized full " synchronous reactance " takes effect. The initial current is several times that which would flow at corresponding unfavorable phase position under operating conditions and lasts long enough to produce electrical and mechanical strains which sometimes result in disaster. By using a value for Z, the impedance, perhaps only 15 to 25 per cent. of normal, and a correspondingly small angle θ, a diagram may be constructed that will properly indicate the dangers of imperfect synchronizing.

For safe and effective synchronizing the circuit may be first closed through a coreless reactance coil of moderate dimensions, as explained in a paper entitled " The Self-synchronizing of Alternators," presented by Mr. M. K. Akers and myself before the Institute in May 1906. The diagram for showing self-synchronizing employs a value for Z about twice the normal, and a large angle θ, and shows that shocks may be eliminated without reducing the useful synchronizing power in the same degree.

Synchronizing Power. The synchronizing power, tending to bring two machines into phase, may be derived from equations 2 and 4.

Equation (2)

$$P' = 1/Z\,[A^2 \cos\theta - A\,B\,(\cos\theta\cos\phi - \sin\theta\sin\phi)]$$

P' positive shows that the load upon machine A tends to retard it.

Equation (4)

$$P'' = 1/Z\,[A\,B\,(\cos\theta\cos\phi + \sin\theta\sin\phi) - B^2\cos\theta]$$

P'' positive shows that the driving upon machine B tends to accelerate it. With P' and P'' both positive (or both negative) the machines are forced together with a power found by adding the two equations:

$$P' + P'' = 1/Z\,[(A^2 - B^2)\cos\theta + 2\,A\,B\sin\theta\sin\phi] \qquad (9)$$

The first term of the second member appears to be negligible, not only because B is usually about equal to A, but also because $\cos\theta$ is small. The synchronizing power is often taken as

$$1/Z\,[2\,A\,B\sin\theta\sin\phi] \qquad (10)$$

If ϕ, the angle between the machine vectors, is the only variable, the value of (10) varies with $\sin\phi$. There is no power acting to hold the machines together, but only to prevent them from moving apart. The effect is a maximum at $\phi = 90°$, and diminishes up to the unstable position of 180°, where it is again zero. The effect, apparently negative beyond 180°, means that the action is to increase the angle toward 360° or 0°.

The above discussion concerns itself only with synchronizing forces. The first term of equation 8 appears negligible, yet its derivation from equation 2 and 4 shows that $1/Z\,[A^2\cos\theta]$ and $1/Z\,[-B^2\cos\theta]$ represent powers acting in the same sense, that is, to retard both machines, A and B.

With angle θ large, as in normal operation, the retarding powers are small, but with Z and angle θ both small, the condition which exists momentarily at the instant of switch-closing, both machines may be so suddenly retarded as to wreck them, since under the condition of small value of θ the braking effect is at its maximum, and the " $A\ B$ " terms of equations 2 and 4 are a minimum. When coreless reactors are used, it is impossible for Z and θ to be small, even momentarily, and the shock to the machines is prevented. No synchronizing effect is obtained without some reactance. The effect is a maximum for large angles of θ. Introducing reactance to increase the angle θ means also an increase in the value of Z, which might result in limiting the current too much. A satisfactory compromise may be effected by trial, but the diagram will indicate readily the proper value of reactance to employ.

There should be a distinction drawn between paralleling alternators, and synchronizing a motor or converter with a distant generator. To bring into action an additional generator, especially when the object is to relieve an overload on the machines in operation, care should be taken not to close the switch with the incoming machine in motor, or " *B* "-vector, position. This will be best accomplished by having the incoming machine running slightly above synchronous speed, and closing the switch not too early. For placing a converter in service, on the other hand, the incoming motor is to receive power, and should not be switched in as a generator or in " *A* "-vector position. This is best accomplished by having the machine running slightly below synchronous speed, and closing the switch not too early.

Comparison with " V-Curves." The loci of *B* for various powers as shown in Figs. 4a, 4b, and 4c correspond precisely with the irregular shaped curves called " phase characteristics " or more commonly " V-curves." In the circle diagram, excitation and current are measured by proper scales radially from *O* and from *A* (a double polar diagram). In the usual form of V-curves the plotting is by rectilinear coördinates. The circle diagram may be rapidly constructed by ruler and compasses, while the V-curves have to be calculated and then carefully plotted. That they are identical will be evident to anyone comparing the diagrams. If the curves are derived from experiment, two observations at given load will suffice to determine the circle with considerable accuracy, while a multitude of observations are needed to prepare a good V-curve. Of course not all observations will fall accurately in an exact circle, but the moderate deviation of normal power loci shows the essential reliability of the circles. It seems possible that a few observations carefully plotted in a circle diagram will serve to determine the " constants " of a transmission line, or of a machine, even better than the usual " synchronous impedance " tests. The method has the advantage of making the measurements under operating conditions.

The use of the circle diagram is not confined to two synchronous machines of single phase. Two or three phases may be represented. Moreover the diagram may be applied to a non-motor load, such as a transformer with any sort of load on the secondary. It suggests a method of graphically estimating the angular phase difference between the secondaries of transformers used for different services, or between the primary and secondary of a single transformer, and at all loads. In the case of a transformer the angle θ charges greatly with the load, and several diagrams might be required where one would suffice in synchronous machine operation. Indeed the use of previously prepared diagrams, or charts, outlined for different values of θ would make the rapid graphical solution of synchronous problems a pleasure instead of a task. The calculations and diagrams assume pure sine curves of electromotive force and current, and some allowance may be required where these curves are distorted.

That the vector relations shown by the circle diagram actually exist, at least approximately, has been recently shown by a mechanical phase indicator attached to two machines running in parallel. The problems involved in the operation of alternating-current machines are often obscure, since the real forces are not subject to direct measurement, and it is hoped that this presentation of the circle diagram will serve a useful purpose in the interpretation of the interaction of synchronous machines.

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25, 1907

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(Subject to final revision for the Transactions.)

POWER-FACTOR, ALTERNATING-CURRENT INDUCTIVE CAPACITY, CHEMICAL, AND OTHER TESTS OF RUBBER-COVERED WIRES OF DIFFERENT MANUFACTURERS

BY HENRY W. FISHER

Probably no form of insulating material for wires has been so frequently discussed as india rubber and its component ingredients, known commercially as " rubber." Very many tests have been devised to determine the percentage of rubber and other materials, and especially the amount of fine para.

In a compound containing both pure para and other grades of rubber, it will probably never be possible to tell the relative percentages of each. If the amount of inferior grades of rubber is considerable, an indication of the fact can be obtained from some of the various tests now used.

Specifications have been devised with a view to securing, by the application of certain well defined tests, an absolutely certain percentage of pure para. In some of these cases the manufacturer could have furnished a better compound containing wax or similar solid hydrocarbons mixed with the dry mineral filler, but the presence of such materials would make it impossible to tell how much of the rubber was fine para.

In view of these rather complicated conditions, several of the manufacturers of rubber-covered wire framed a set of specifications which would ensure 30% para and give at the same time latitude to the manufacturer to use such other ingredients as in his experience would make a compound having toughness, elasticity, resistance against high voltages, and other desirable qualities. These specifications were brought to the attention of the Institute in a paper by Mr. Wallace Clark, read in New York on April 27, 1906.

The object of the present paper is to give the results of certain tests which, while not strictly new, have not been applied commercially to rubber-covered wires. One reason for conducting this investigation was to see if power-factor tests would not give an insight into the qualities of different makes of rubber-insulated wire.

The definition of power-factor as here used is the ratio of the power absorbed in the rubber compound to the apparent loss as found by multiplying the charging current by the applied volts. Practically speaking, it may be considered as an indicator of the loss in the dielectric around the wire and therefore a low power-factor is desirable.

A considerable amount of work has been done by various experimenters to determine how the losses in condensers and cables vary with the applied volts, frequency, capacity, etc. One of the most recent investigations of this sort was given in the paper of Dr. Paul Humann which appeared in the " Elektrische Bahnen U. Betriebe," from August 24 to September 24, 1906.

Dr. Humann's formula for the loss in the dielectric of paper-insulated cables is as follows:

$$W = K E^2 n C$$

Where W = the loss in watts,
K = a constant varying with different insulating compounds,
E = the effective pressure in volts,
n = the frequency of the alternating current,
C = the inductive capacity of the cable.

The proof of the above formula is as follows:

$$\text{power-factor} = p.f. = \frac{W}{I\,E} \tag{2}$$

$$I = \text{the changing current} = \frac{2\pi\,n\,C\,E}{10^6} \tag{3}$$

Substituting and transposing,

$$W = \frac{p.f.)\ 2\pi_2}{10^6} E\,n\,C = K\,E^2\,n\,C \tag{4}$$

Where $K = \frac{(p.f.)\,2\pi}{10^6}$. The loss is in watts and it varies in direct proportion to the frequency, capacity and power-factor and to the square of the electromotive force.

The methods adapted by Dr. Humann were somewhat involved and complicated, but nevertheless ingenious. In order to get true readings he had to expurgate the harmonics of the alternating-current voltage, producing thereby a true sine-wave electromotive force.

The writer is much indebted to Dr. Rosa, of the Bureau of Standards, for outlining some extremely simple methods to determine power-factors, capacities, inductances, etc. This led to the design of a special form of bridge having non-inductive resistances with minimum inductive capacities, and suitable binding-posts for the various apparatus employed. The rest of the outfit consisted of a vibration galvanometer, and a motor-generator the speed of which was kept absolutely constant by an electrically driven tuning-fork. The rate of vibration of the tuning-fork could be varied by the application of weights near the end of the forks.

By careful adjustment of both the tuning-fork and galvanometer they could be brought into synchronism, when the latter becomes a most sensitive instrument for indicating minute alternating currents. Moreover, as the galvanometer needle responds only to the fundamental period of the alternating-current circuit, and is not at all affected by existing harmonics, it is unnecessary to employ a sine-wave electromotive force for measurements of capacity, inductance, and power-factor.

The method employed in these researches is based on the fact that a cable or condenser, the absorption and leakage of which is not zero, is equivalent to a cable or condenser with zero absorption in series with a resistance, called the "equivalent resistance," such that the angle of lead between the electromotive force and current shall be $90°-\theta$.

With a perfect condenser $\theta = o$. The power-factor $= \cos(90-\theta) = \sin\theta$ (5)

Fig. 1 shows the diagram of the connections and arrangement of the various instruments.

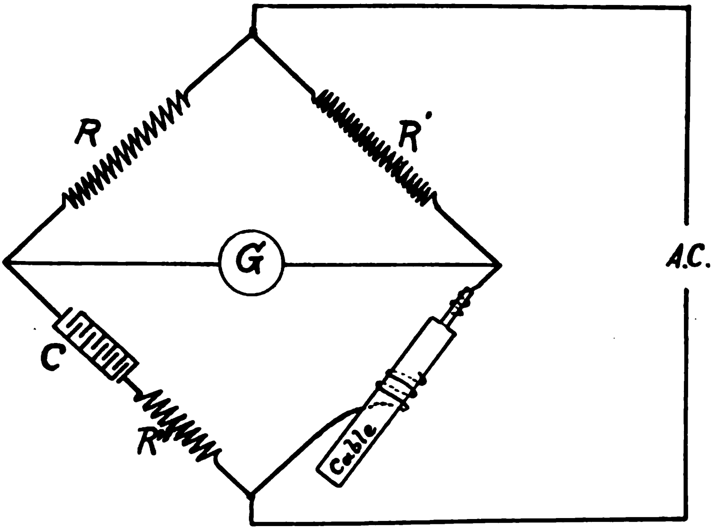
R and R' are the ratio arms of the bridge; R'' is the resistance which is placed in series with the standard condenser C; $A.\ C.$ is the alternating-current source; and G is the vibration galvanometer. The plan of procedure is first to vary R or R' until a partial balance is obtained, then adjust R'' and R until the galvanometer mirror ceases to vibrate, when the power-factor of the cable =

$$\text{Power-factor of condenser} + \frac{2\pi\, n\, R''\, C}{10^6} \qquad (6)$$

and capacity of cable $= \frac{R}{R'} \times C$

Where n = the cycles per second and C = the capacity of the standard condenser.

FIG. 1.



The reflection from the galvanometer mirror of a lamp filament was used until a balance was practically obtained, then the reflection of a scale was observed, and the resistances varied until the scale divisions were sharp and well-defined.

This method is so extremely sensitive that in making tests of cables it was generally impossible to adjust the bridge for any length of time so that the galvanometer mirror did not vibrate. There is apt to be a continual slight variation in capacity and power-factor. With perfect standard condensers, capacities can be compared to within one point in 5000.

Owing to some peculiar factory vibration which affected the vibration galvanometer, it was impossible to make the tests at a frequency of 60 cycles per second as originally intended, and

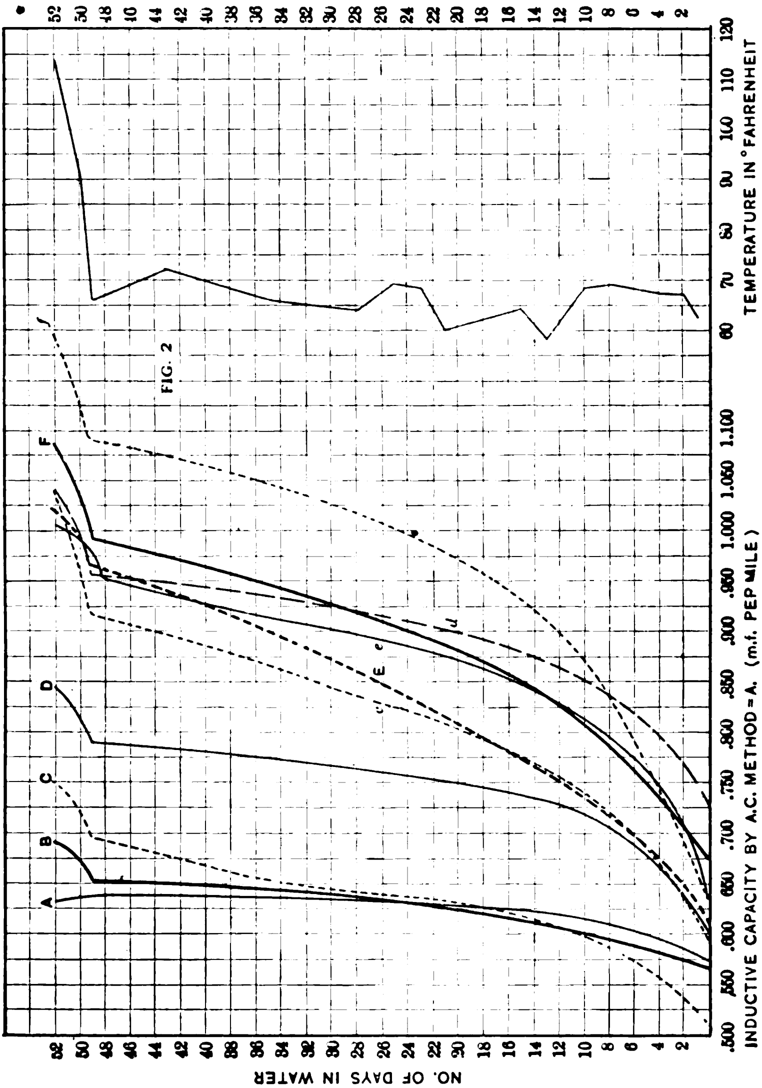


FIG. 2

hence after considerable adjustment a frequency of 53.5 cycles was employed throughout the tests.

Coils of rubber-covered wire of various manufacturers were purchased in different cities. These were cut into lengths of 210 ft. and placed in a metallic tank which was afterwards filled with a strong saline solution. Each curve represents therefore the results of tests on two or more coils of wire.

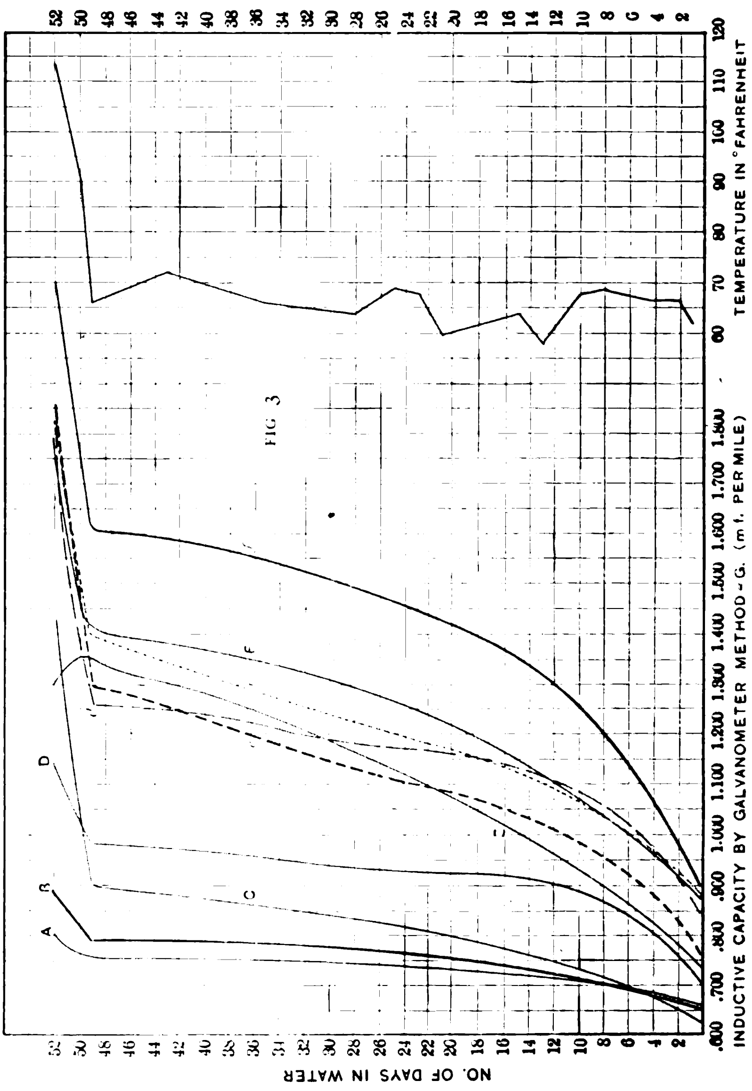


FIG. 3

The voltage tests were made on four samples of each original coil. The samples were four feet long, three feet of which was under water for 24 hours before the test was applied. Samples of each coil were reserved for chemical analysis, but owing to the time required for this work returns were not received from all coils. Sufficient tests were made, however, to permit of a general comparison between most of the samples.

Table 1 gives the general dimensions of the rubber-covered wire and the average break-down voltage tests.

Table 2 gives the results of the chemical analysis. The different samples are represented by letters, and the different materials by numbers.

TABLE NO. I.
DIMENSIONS AND BREAK-DOWN VOLTAGES OF SAMPLES.

Sample Letter	Size of Wire B. and S. G.	Diameter in mils over Braid	Diameter in mils over Rubber	Thickness of Rubber	Break-down Voltage
A	10	323	209	53.5	22860
B	10	280	204	51	23100
C	10	293	209	53.5	15960
c	10	302	202	50	14450
D	10	303	213	55.5	16750
d	10	292	205	51.5	16300
E	10	285	194.5	46	13600
e	10	303	201	49.5	16770
F	10	300	209	53.5	22040
f	10	306	209	53.5	15120
G	10	245	195	46.5	23600
H	10	249.5	193.5	45.75	18355
h	10	246	197	47.5	12825
I	10	252.5	199	48.5	17775
i	10	257	201	49.5	18650
J	12		235	77	23035
K	12		234	76.5	22500

Chemical tests of rubber are difficult to make, and owing to the fact that several of the ingredients are slightly soluble in solvents other than those particularly used for each, there is a possibility of slight errors in the amount reported. No. 2 is the acetone extract and No. 3 the pyridine extract. The tests were most carefully made each in the same manner and by a person the accuracy of whose analysis had previously been checked by his reports of samples having known ingredients.

In designating the wire of any one manufacturer the large character represents the higher priced wire and the small character

TABLE II

Specific Gravity and Composition of Rubber

Material Number.	Name of Material	Sample Letter and % of Material																
		A	B	C	*c*	D	*d*	E	*e*	F	*f*	G	H	*h*	I	*i*	J	K
	Specific Gravity	1.75		1.76	1.86	1.86	1.97	1.66	1.81	1.91	2.02	1.75	1.79		1.74	1.77		
1	Rubber (H_{16} C_{18})	26.84		23.32	22.42	20.64	15.52	16.67	16.72	20.12	17.20	27.32	21.85		23.33	22.43	28.30	27.96
2	Free oils, Resins, Waxes Solid Hydro-carbons	4.71		9.92	9.75	5.80	7.17	17.99	10.90	4.69	3.61	3.49	6.10		7.04	7.45	3.70	2.99
3	Pitch, Tar, Bituminous Substances	2.16		1.54	1.29	2.86	2.90	3.41	3.59	1.80	2.62	1.79	2.22		2.98	1.99	0.375	0.375
4	Ether Extract	0.300		0.915	0.97	1.22	0.64	0.34	0.27	0.35	0.47	0.51	0.35		0.50	0.73	0.55	0.28
5	Blown oils Fatty Matters	0.81		0.66	1.02	1.15	1.85	2.02	0.83	0.90	0.44	0.18	0.60		0.18	0.74	0.32	0.00
6	Combined Sulphur	2.41		3.41	5.08	3.83	4.26	5.47	3.48	4.45	3.01	3.01	3.37		3.64	3.65	2.50	2.62
7	Free Sulphur	0.23		0.56	0.46	0.20	0.20	0.44	0.71	0.20	0.27	0.24	0.32		0.25	0.25	0.32	0.40
8	Organic Matter (soluble in water)	0.38		0.67	0.97	0.43	0.67	0.90	0.78	0.68	0.64	0.43	0.78		0.66	0.75	—	—
9	Moisture	0.14		0.24	0.46	0.30	0.210	0.25	0.57	0.21	0.15	0.34	0.34		0.20	0.43	0.41	0.310
10	Mineral Matter	62.03		58.77	57.58	63.60	66.61	52.53	62.16	66.62	71.61	62.71	64.08		61.22	61.60	63.53	65.38

of the same letter the lower priced wire of the same manufacturer.

The measurements made, which are represented by curves were as follows.

A, the inductive capacity by alternating-current method;

G, the inductive capacity by the ballistic-galvanometer method;

The insulation resistance after one minute's electrification by direct deflection method;

P. F., the power-factor;

W, the total loss at a frequency of 53.5 cycles and electromotive force = 75 volts.

For convenience in comparison the loss *W* is multiplied by 50, making it equal to that of 50 miles of wire, when the lowest loss is about one watt.

Owing to the time required to complete these tests it was necessary to make two sets of measurements on two different lots of wires and hence the reason for two sets of curves. On account of the great variation in insulation resistances, two sheets with different scales had to be used. These are given in Figs. 4 and 5, and to get a relative comparison between the two sets of curves the insulation resistance of wire *e* is shown in both figures.

On the right-hand side of each set of curves is given the variation of temperature with time. It was impracticable to keep the temperature at the same point throughout the tests, but the variation in temperature would make little difference in all the various tests, except possibly those of insulation resistance. As the variation of temperature was alike with all coils, the relative average results may be considered sufficiently correct for the purposes of this paper, which deals with comparisons rather than with absolute values. The last two tests were taken at temperatures of about 90° and 115° fahr., thus affording a chance of comparing the various temperature coefficients.

Some explanation of the curves represented by the term A/G is here necessary. This is the ratio of the inductive capacity measured by the alternating-current method to that measured by the usual galvanometer method. In a paper by the writer, read two years ago at the Asheville convention, the statement was made that the dielectric loss in a cable seems to increase as the above ratio becomes smaller. This appears to be generally true here, too.

Inductive capacities are usually measured by the ballistic galvanometer method and A/G is the factor by which said capacities must be multiplied in order to get the true alternating current capacity.

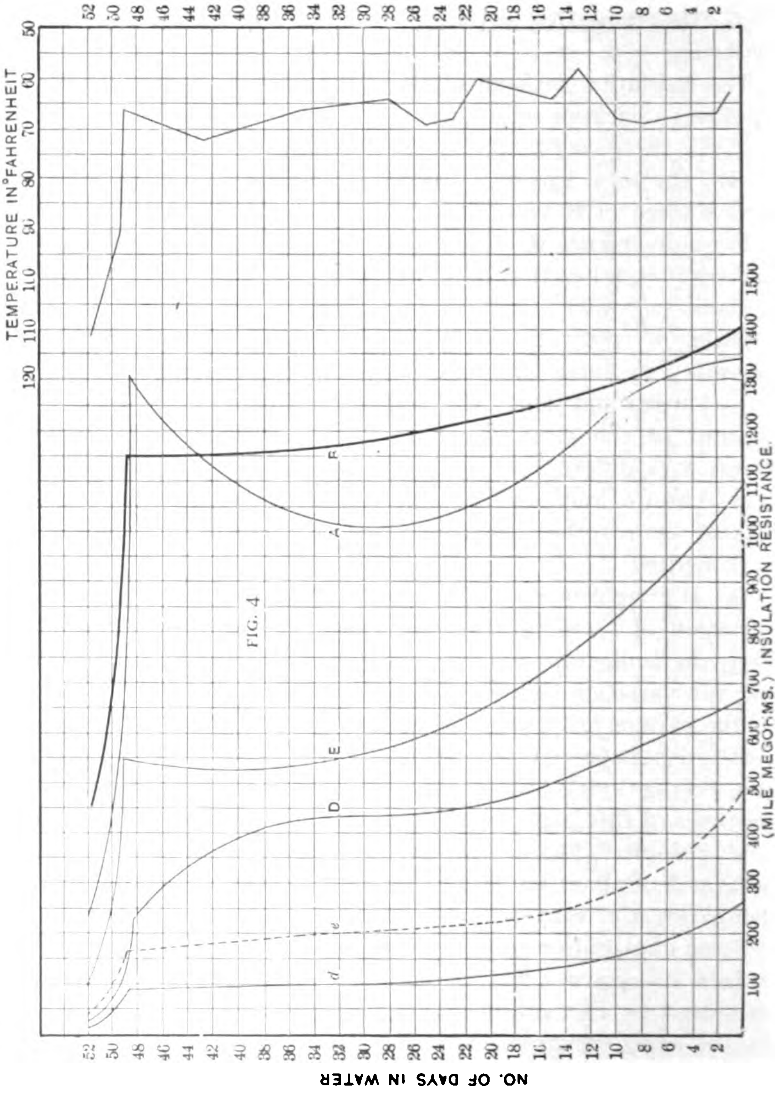


FIG. 4

In a paper of this kind which deals with so many different tests, perhaps the most difficult undertaking is the attempt to make correct deductions and comparisons. For the present confining our remarks to Figs. 2 to 8 inclusive, it is at once noticeable that the insulation resistance, power factor, and A/G decrease with the time of immersion in water, and the others increase

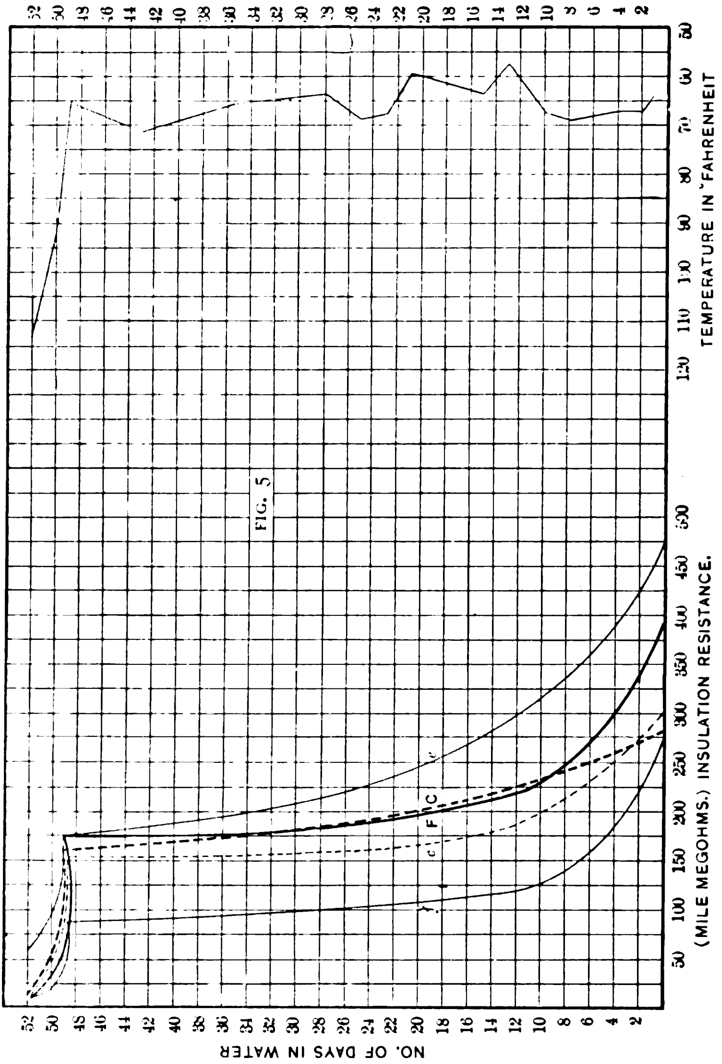


FIG. 5

with the time of immersion. This is what one would naturally expect because all the samples were braided and therefore the water would take some time to fill all the interstices around the rubber.

It is also evident that the rate of change is generally less where the percentage of rubber is high, as with samples *A*, *B*, *C*, and *D*. *B* was not analyzed, but it evidently contained a large percentage of rubber.

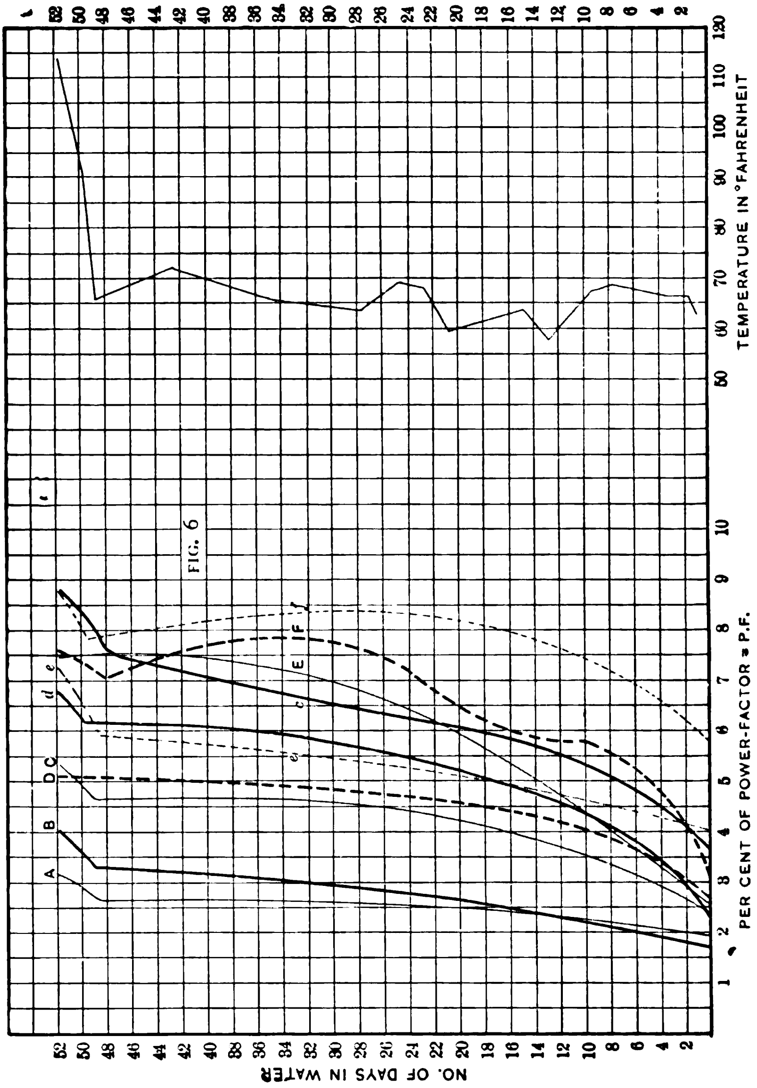


FIG. 6

It will also be seen that while the curves do not always follow in the same order, yet there is a certain amount of regularity among them; for instance, *A* and *B* are at one extreme and *f* at the other. The general tendency is for the insulation resistance to vary inversely as the capacity. There are, however, some notable exceptions which will be considered in due time.

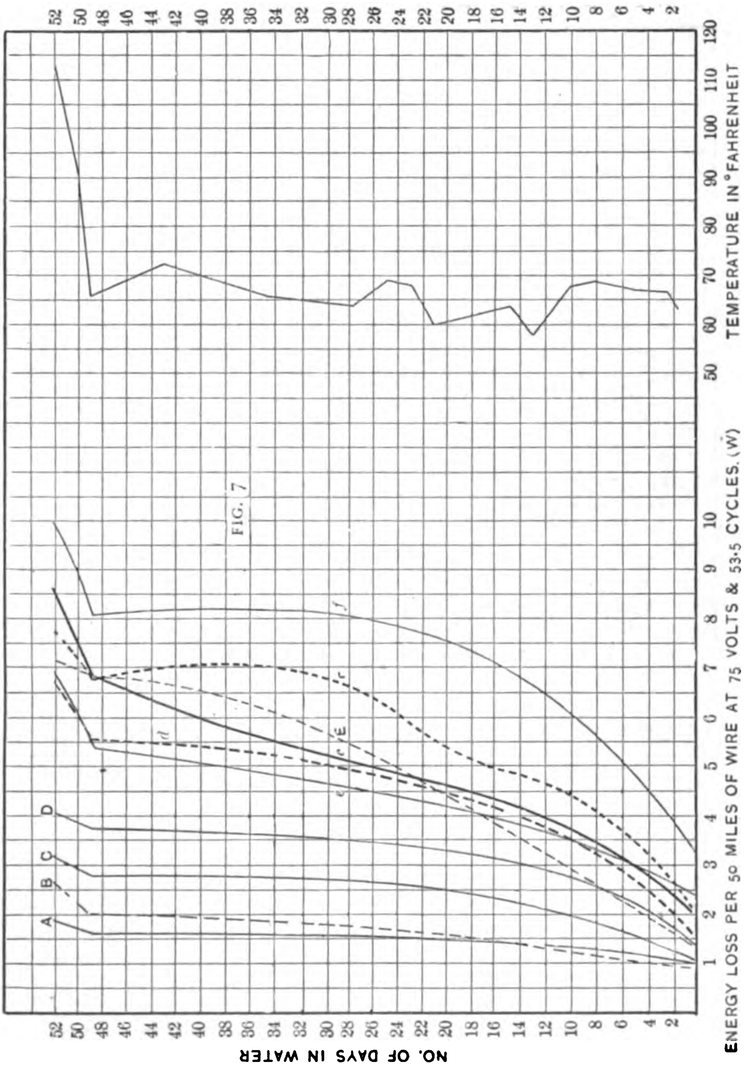


FIG. 7

We may here ask the pertinent question; what are the desirable qualities of a rubber insulating compound? This might be answered as follows: 1, good materials and uniformity of structure; 2, great electrical strength; 3, good lasting properties. Insulation and capacity tests give us some idea of the first, high-voltage tests of the second, and while long-time tests are essential for the third, yet power-factor or loss-tests

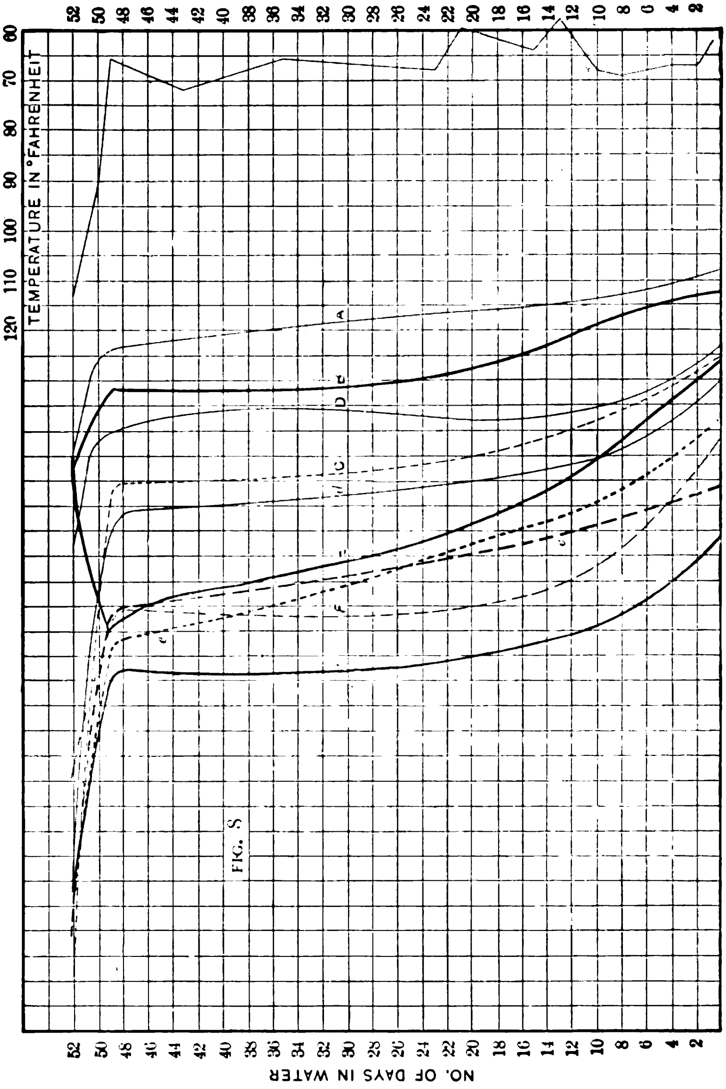
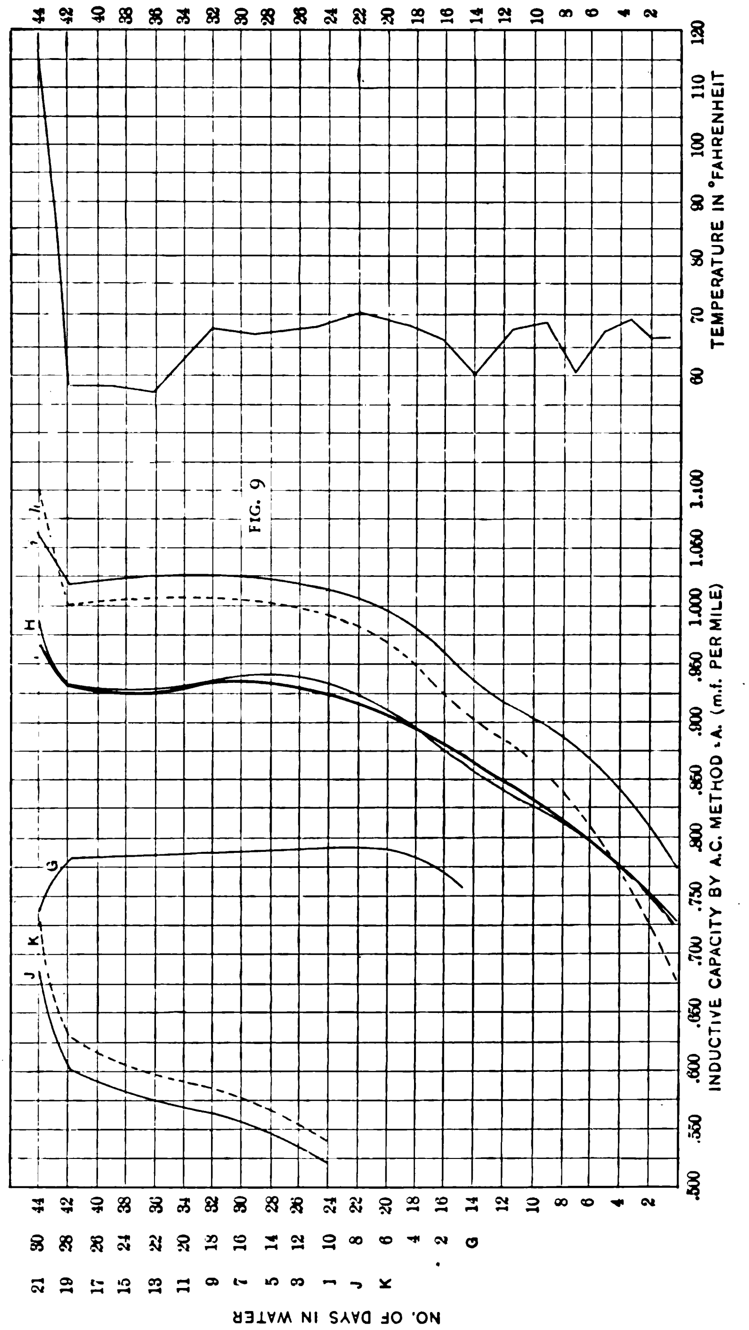


FIG. 8

covering a shorter period of time may indicate any tendency to gradual disintegration.

Now making some general comparisons, we find that *A* and *B* have high insulation resistance, high resistance to voltage, small



TEMPERATURE IN °FAHRENHEIT
60
70
80
90
100
110
120
INDUCTIVE CAPACITY BY A.C. METHOD A. (m.f. PER MILE)
.500
.550
.600
.650
.700
.750
.800
.850
.900
.950
1.000
1.050
1.100
NO. OF DAYS IN WATER
44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2
30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 G
21 19 17 15 13 11 9 7 5 3 1 J K
J
K
G
H

FIG. 9

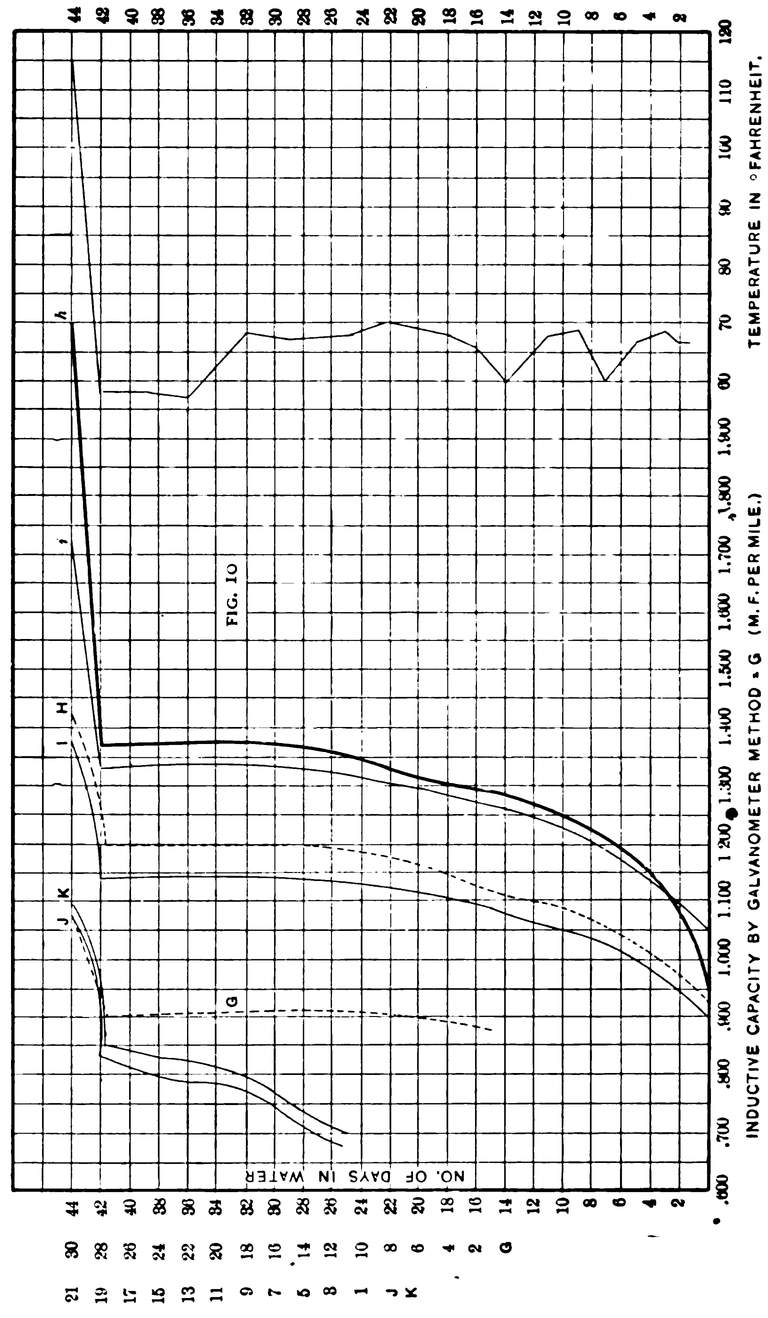

TEMPERATURE IN °FAHRENHEIT.
60
70
80
90
100
110
120
INDUCTIVE CAPACITY BY GALVANOMETER METHOD = G (M.F. PER MILE.)
.600
.700
.800
.900
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800
1.900
NO. OF DAYS IN WATER
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
G
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
K
J
1
3
5
7
9
11
13
15
17
19
21
h
i
H
I
K
J
G

FIG. 10

energy loss, and *A* shows a higher percentage of rubber. *F*, on the contrary, while having about equally good resistance to voltage, has much less rubber, much less insulation resistance, and greater energy loss. The percentage of rubber in *C* lies about midway between *A* and *F* and yet *C* withstands much less voltage, has an insulation resistance about equal to *F*, but the energy loss is nearer that of *A* than that of *F*. In trying to account for this we see that *A* and *F* have about the same combined amount of materials 2 and 3, while *C* has almost 4% more of those materials. It therefore seems that the addition of too much waxes, pitches, etc. is not beneficial.

The most notable cases of excessive amounts of materials 2 and 3 are *E* and *e*. *E* withstood the lowest voltage test but this may be entirely due to its thinner rubber wall, and yet its insulation resistance was third from the highest. This shows that the insulation resistance does not depend entirely on the amount of rubber. *C* had 23% rubber and *E* about 17%, and yet the insulation resistance of the latter was best. The energy loss of *E* however, was much greater than that of *C*. The writer fully realizes that some of these differences may be partly due to the quality of the rubber employed.

Through an oversight, the letters *E* and *e* were reversed, *e* being the higher priced compound and *E* the cheaper grade. In all the figures except those giving power-factor and energy loss, *e*, the better grade, is further from *A* than *E*.; *e* withstood a higher voltage than *E*, and hence with these wires the energy test and voltage test were the true indications of quality.

D and *d* are consistent throughout the whole series of curves, and yet the break-down voltage of *D* is not as high apparently as one would expect.

The writer can give no definite reason why *F* and *f* should almost invariably test worse than the other samples. In break-down voltage tests they were practically as good or better than first and second grades of other wires. The use of an inferior grade of rubber might partly account for it, but because of the high dielectric strength of *F*, the writer is of the opinion that the materials 2, 3, and 5 employed, had properties which made the insulation resistance low, the capacity high, and the energy-loss and power-factor high. The writer is fully aware of the fact that insulation, resistance, and capacity are affected by the conditions and time of vulcanization, which might be the cause of some of these discrepancies. It is hardly likely, however, that

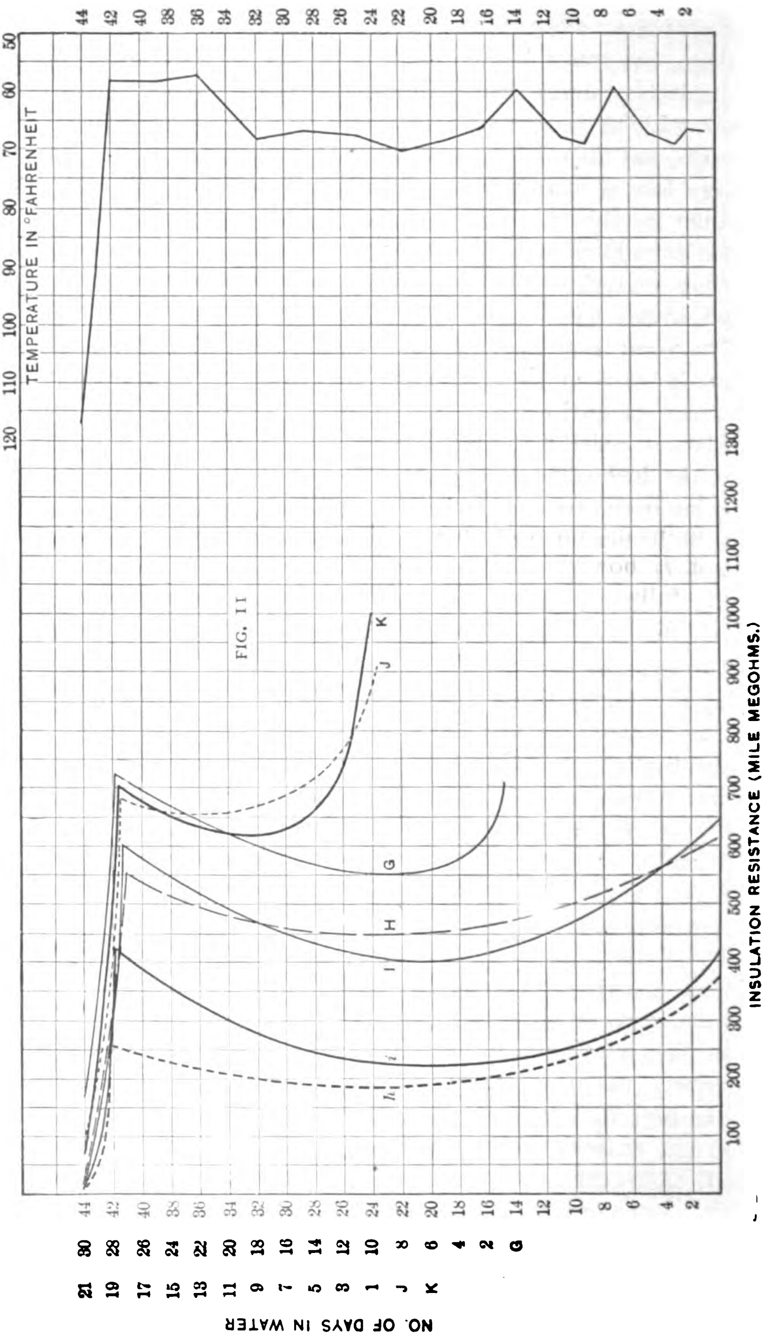

TEMPERATURE IN °FAHRENHEIT
50
60
70
80
90
100
110
120
INSULATION RESISTANCE (MILE MEGOHMS.)
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2
K
J
G
H
I
i
h
30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 G
21 19 17 15 13 11 9 7 5 3 1 J K
NO. OF DAYS IN WATER

FIG. 11

F and *f* were vulcanized at the same time, and hence the theory of slightly defective material is probably the nearest correct.

It is interesting to note the peculiar change of insulation resistance of sample *A*. There was first a gradual decrease and then an increase to the time when heat was applied, when the insulation again became less. After rubber covered wire is vulcanized, there seems to be a tendency for the insulation resistance to increase and the capacity to decrease. This probably accounts for the above effect. There are other samples which show this tendency to improvement after the lapse of time, but in a less marked degree.

Referring once more to the break-down voltages, it is well to bear in mind the fact that long coils of wire will not withstand anything like the break-down voltages which punctured the four-foot samples. In a few cases, some of the four-foot samples broke down at a much lower voltage than the average of the others made by the same manufacturer.

The second lot of samples are designated as follows: *G*, *H*, ***h***, *I*, *i*, *J* and *K*. The curves representing tests made on these are found in Figs. 9, 10, 11, 12, 13, and 14.

Samples *H*, *h*, and *I*, *i* were tested for 14 days when two samples, the average of which is given by the *G* curves were put in the same tank. At the end of 23 days, the samples *K*, *L* were put in the tank. There are therefore, three sets of time figures, but under two of these are placed the letters of the samples to which they refer, and the third set must be used for *H*, ***h***, *I*, ***i***.

The sample *G* seems, from the chemical analysis, to be reasonably close to 30% rubber. The thickness of rubber is the smallest, and yet the break-down voltage was the largest.

All the curves of *G* show but a slight tendency to variation after the lapse of a few days, and there is a general indication of a gradual improvement with time.

The insulation resistance of *G* is not so high as that of *A* and *B*. This difference is partly accounted for by the difference in the rubber wall, and partly by the amounts and kind of materials 2 and 3. The power-factor and the energy-loss of *G* are also greater than those of *A* and *B*, but this is probably partly due to the smaller amount of materials 2 and 3. (See remarks later on about *J* and *K*.)

All the insulation resistances given in Fig. 11 become better near the end of the tests; this is partly due to a drop in temperature which occurred for the two tests prior to increasing the

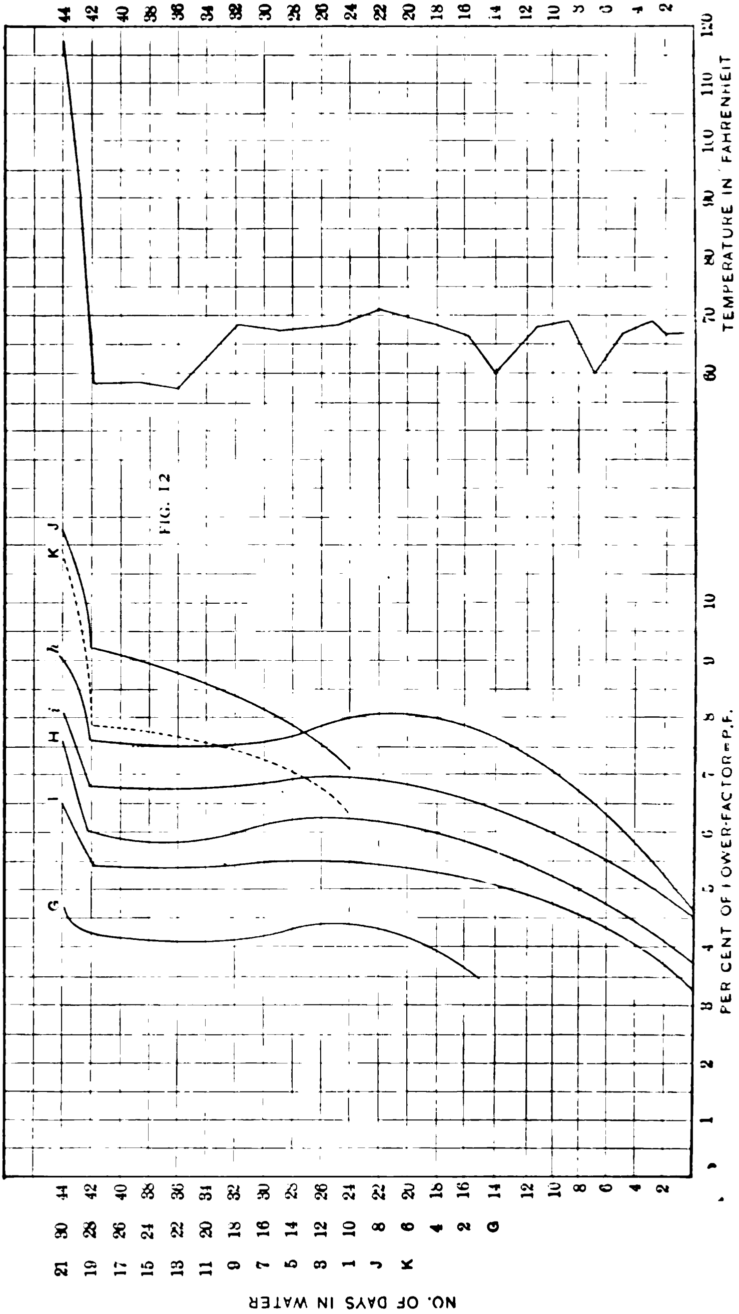

44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2
30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 G
21 19 17 15 13 11 9 7 5 3 1 J K
NO. OF DAYS IN WATER
1 2 3 4 5 6 7 8 9 10
PER CENT OF POWER-FACTOR = P.F.
60 70 80 90 100 110 120
TEMPERATURE IN FAHRENHEIT
J
K
h
i
H
I
G

FIG. 12

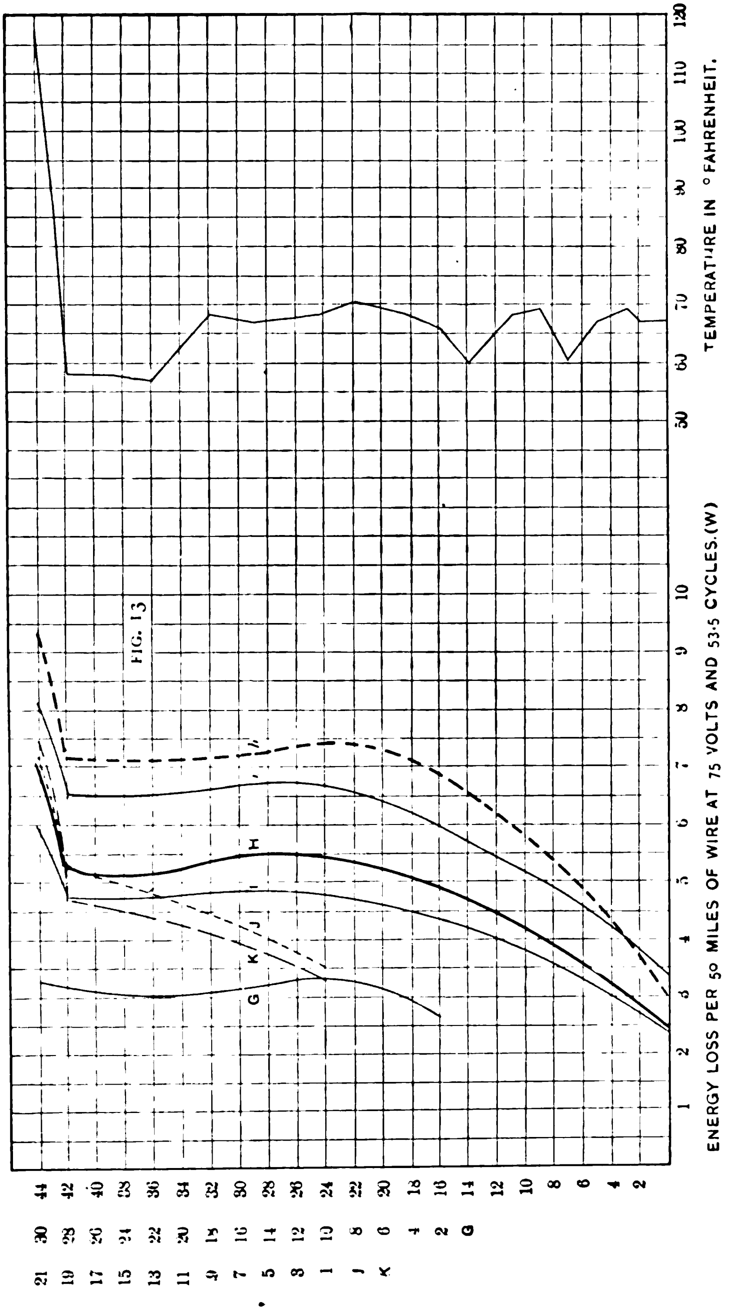

TEMPERATURE IN °FAHRENHEIT.
50
60
70
80
90
100
110
120
ENERGY LOSS PER 50 MILES OF WIRE AT 75 VOLTS AND 53·5 CYCLES.(W)
1
2
3
4
5
6
7
8
9
10
H
I
J
K
G
44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2
30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 G
21 19 17 15 13 11 9 7 5 3 1 J K

FIG. 13

temperature at the end of the series. There is sufficient evidence, however, to show that before the above happened, the insulation resistance of all these samples had ceased to drop, and, in fact, was slightly improving. This is probably because all the samples analyzed had over 20% of rubber. Some of the insulation resistance curves are odd in appearance, but this may to some extent be due to errors or surface leakage. In measuring the insulation resistance of only about 200 ft. of wire, a high degree of accuracy cannot be expected.

"*I*," contained slightly more rubber than *H*, and in most cases the former tests best. In like manner, *i* is better than *h* in the larger number of curves: *h* was white-core and this may partly account for its low break-down voltage.

c, *d* and *f* were also white-core rubber, and the break-down voltages of these were also among the lowest. The white-core part of the insulation was not analyzed, the reported ingredients being those contained in the black-rubber portion.

And now, we come to curves *J* and *K* which are perhaps the most interesting of the series. *J* was made of 15% fine para rubber and 15% african rubber. *K* had 30% fine para. The rest of the materials in both samples was about 1% wax and dry mineral matter. The analysis does not show quite 30% rubber, but this is partly due to the extractive matter contained in the rubber. On all sheets curves *J* and *K* are reasonably close to each other.

The power-factor and energy loss of *K* are less than those of *J*. Several of the curves are, however, erratic in appearance, showing a tendency to an unstable condition.

In two prominent points, break-down voltage, and power-factor and energy-loss, these samples are inferior to *A*, *B* and *G*.

1. *Break-down voltage.* The thickness of rubber on the samples *J* and *K* was about 50% more than that of the other wires, and yet the break-down voltage of *J* and *K* was about the same as those of *A*, *B* and *G*.

Thinking that this might be partly due to the greater electric density around the smaller wire (No. 12) which formed the conductor of *J* and *K*, the writer tested several samples of No. 14 wire with 51 mils rubber wall, containing about 22% rubber; the average break-down voltage was 19,000 volts, which agrees closely with the other sample containing about the same amount of rubber.

2. *Power-factor and energy loss.* The tests of *J* and *K* were

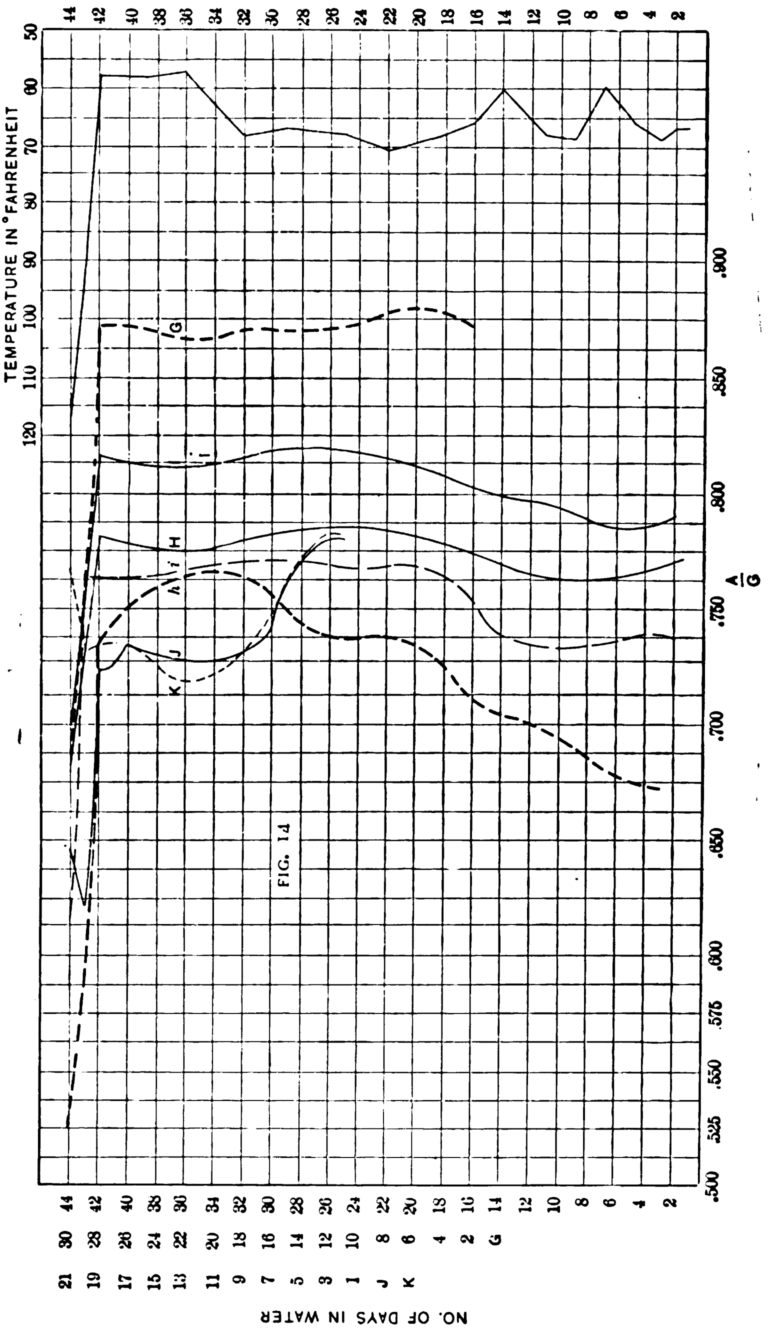

TEMPERATURE IN °FAHRENHEIT
50
60
70
80
90
100
110
120
A/G
.500
.525
.550
.575
.600
.650
.700
.750
.800
.850
.900
44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2
30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 G
21 19 17 15 13 11 9 7 5 3 1 J K
NO. OF DAYS IN WATER
G
H
h
i
J
K

FIG. 14

not carried on for so long a time as those of the others, and yet the power-factors were greater at the end of the series than those of any of the others, and there was a marked indication of still further increase.

The energy-loss of *J* and *K* is not so great as that of some other wires; this is due to the fact that the capacity of *J* and *K* is much smaller on account of their greater thickness of rubber. No doubt if these samples had a thickness of rubber of about 50 mils they would have tested worse in most respects than any of the samples of the series.

It therefore appears that the addition of certain materials to a rubber-insulating compound (containing say 30% of rubber), which upon chemical analysis will show a high percentage of extractive matter, may result in a much better quality of rubber-insulating material than one composed of 30% para and showing but a low percentage of extractive matter.

This paper has been prepared in great haste and therefore matters of importance may have been overlooked or omitted. In conclusion, the writer wishes to express his appreciation of the ample facilities afforded him for this investigation, by the Standard Underground Cable Co. He also wishes to acknowledge the valuable assistance rendered by the following persons: Messrs. H. D. Shakarian, T. D. Waring, H. Barbour and G. D. Eustachio.

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25, 1907.

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(Subject to final revision for the Transactions.)

PROTECTIVE APPARATUS ENGINEERING

BY E. E. F. CREIGHTON

The main object of this paper is to describe the methods which have been in use in the development of lightning apparatus, so that some or all of these methods may be adopted or recommended as standard in the investigation of the value of any particular apparatus. As an introduction, it is pertinent to point out the differences and identities in the operation of the arrester in test as compared with its operation in actual service. Generators, motors, arc lights, practically all electrical apparatus except lightning-arresters—are tested under the conditions, under which they are to operate. The lightning-arrester in service comes into action only intermittently, with long intervals between operations, and each operation is under conditions more or less different from the previous ones. It protects, fails, or is destroyed according to its adaptation to meet the imposed conditions. The arrester may operate for years before it encounters conditions which it is incapable of meeting. The conditions which caused the failure are usually unknown, therefore little or no progress can be made in the design without studying the actual conditions which caused the failure of the arrester. Since this cannot be done at present with cloud lightning, we must experiment with artificial lightning in the laboratory until this condition causing failure is found. Simply noting whether an arrester fails and then making an adjustment, elimination, or addition of parts of the arrester is a cut-and-try method and has already been carried to the limit of its efficacy in the development of protective apparatus.

In making a plea for the recognition of the value of laboratory tests, it is pertinent to look at the subject from several viewpoints. Lightning-arresters are but auxiliary devices to the large expensive machines of electrical transmission systems and the receipts therefrom to the manufacturer are small in proportion. The successful and continuous operation of electrical systems, however, depends greatly upon the efficiency of the protective devices. Great expenditures have been made in the development of protective apparatus, not on account of the intrinsic commercial value of the arrester business, but on account of the broader scope it gives to the electrical industries. Station managers should realize that to them has been given each year the very best apparatus that could be developed, and that the manufacturer of large apparatus is even more desirous than they to install an arrester which operates perfectly. Failures of arresters are comparatively infrequent, and in order to eliminate these last faults the intelligent coöperation of many station managers is desirable. In a short time instructions and apparatus for studying the operation of lightning arresters in service will be ready to send to managers, and conscientious efforts of many will show the rare instances where the arrester fails and will indicate the complete solution of the problem. If the insulation of electrical apparatus has been seriously deteriorated by overheating, a manager should make an effort to ascertain this fact and not befog the problem by laying the fault to the arrester. Furthermore, there is always a necessity for engineering in the choice and location of arresters to give the best conditions of protection.

Up to the present the design of electrical transmission apparatus and that of protective apparatus have gone hand in hand. For example, when the arrester was adjusted to its maximum permissible sensitiveness and failed to protect the end-turns of a transformer, the transformer designer came to the rescue by adding extra insulation to the end-turns. At present the designers of protective apparatus are endeavoring to design arresters for each potential that will limit the rise to 150% of normal. That arresters have been faulty is conceded, but the designer has too often to meet the condition of weak insulation and the occurrence of rare lightning phenomena. The problem is further complicated by the varied demands of protection at different voltages of transmissions.

A brief survey of the relation of line voltage to the problem of protection is herewith given.

Line potential and the problem of protection. As a thunder-cloud approaches a transmission line, each lightning discharge increases the severity of the induced stroke on the line. In this wide range of intensity it is easy to imagine that there is an average value of potential, due to discharges to the earth within a mile of the line, and yet not actually striking the line, which occurs frequently. Its value is unknown, but, judging from the fact that it does not jump over the insulators, it is less than the spark-potential of the insulator and therefore, in general less than 200 kilovolts. The indications are, however, that it is probably not less than 100 kilovolts.

The thunder-cloud takes no account of the potential of the line, so that a 500-volt trolley wire will get the same induced lightning stroke as a 60-kilovolt transmission in the same location. 100 kilovolts would be harmless to the insulation of the 60-kilovolt line, but an arrester must operate instantly and rapidly on a low-voltage line to bring this potential down to a safe value before the relatively weak insulation is damaged. On high-potential lines, furthermore, the brush discharge potential of the line conductor is not much above the line potential, so abnormal potentials may lose an appreciable part of their dangerous peak values through the energy thus lost in the atmosphere. There is one compensating condition in the protection of low-voltage systems, in the greater factor of safety in the insulation customarily used in the construction. It is not unusual to find a 2,000-volt transformer with a factor of safety of 5 to 10 and a lightning-arrester with a spark potential of twice normal, whereas a 60-kilovolt transformer may have a factor of safety little greater than two, and the arrester must be adjusted within this limit.

Effect of location of circuits on the problem of protection. There is another compensating condition favoring the design of arresters for low-potential circuits; namely in the shorter lengths and favorable locations, both due to natural engineering requirements. For example, 2300-volt circuits are usually short and confined to the streets of a city where the houses and overhanging trees protect the lines from lightning charges induced by the storm clouds. Trolley wires are often overhung with feeders and have an additional compensation in leaky insulators. The numerous supports of the trolley wire each with a low-insulated, leaky-surfaced insulator help to discharge the static electricity to ground at the point where it is freed. Unfortunately, 2300-volt circuits and trolley lines are not confined to shady avenues and city streets, but are often carried into the open country. This is the part of the circuit which needs special care and protection against cloud lightning. A striking illustration of this necessity was shown last summer at a coast city. The city trolley was connected with a beach line. A storm passed over the city, disabling more than a dozen cars on the beach but none of the cars on the city streets. All these cars carried arresters of antiquated design. Another trolley circuit, an interurban, in a lightning storm district passes along miles of road with many large trees on each side. In consequence, with the ordinary protective apparatus, burn-outs of motors from lightning are so infrequent as to cause no disturbing increase in the repair expense.

Factor of damaged insulation. In the matter of satisfactory protection a factor enters which is beyond the control of the lightning-arrester designer. This is the effect of the abuse of the insulation of electrical apparatus. These abuses are usually confined to overheating and wetting the insulation. Overheating produces a gradual weakening which will finally cause a short-circuit even at normal voltages. This final catastrophy, if due to normal voltages, will not be affected by the presence of the lightning-arrester, but the arrester, according to its efficiency, will lengthen the time during which the insulation can withstand abnormally high potentials.

Guarantees. Because of the necessity for the insertion of a conditional clause stating that the insulation has not deteriorated, no form of useful guarantee that the arrester will protect the insulation can be given by the manufacturer, even when an absolutely perfect and universally applicable lightning-arrester is in commercial service. A guarantee that an arrester will not be destroyed within a given time, say one year of service, could be given, but it would put a premium on making the arrester safe, even at the expense of the apparatus, and is therefore objectionable.

Regarding service tests. The final criterion of success of an arrester is infallible protection under every condition of service. Perfect operation in one location does not prove the success of an arrester unless it can be shown that the lightning in that location was severe and of widely variable nature. There is an element of luck with storm-centers away from the line; specially high factors of safety of insulation, favorable location of lines, and freedom from resonant conditions must be taken into account. A considerable expenditure of money and time must be made before any conclusion can be drawn from a service test. The information from a laboratory test, while not final in its conclusions, gives immediate results and brings an earlier solution.

Trouble inspection. Furthermore, the service test alone gives no information regarding improvement of design. If the arrester is destroyed, the designer is often called in to inspect and investigate the cause of the trouble. There are perhaps a few pieces of fused metal, arc holes, broken chunks of porcelain, burned insulation of the leads, and a disgruntled manager. The results are visible. The cause of the trouble disappeared as rapidly as the air vibration of explanation. One goes over a series of possible causes like the presence of bugs, bad condition of the arrester due to previous operation, and lack of inspection, collection of dirt on the bushings, grounded phase, direct stroke, line-to-line surge or line-to-ground surge, standing wave, and faulty design. On the other hand, if the failure of the arrester was the failure to protect the apparatus, speculations are made on the nature of the stroke of lightning, its natural frequency, duration, quantity of electricity, standing wave, and resonance. If the puncture was internal, there is sometimes the question of abnormally weak insulation due to poor workmanship, or abuse in the form of overheating, wetting or mechanical injury. Possibly the arrester was not at fault. If the trouble was a standing wave, it might have been in a poor location to protect. The earth connection may have been bad, and so on.

If the insulation was punctured at the bushing, or the spark jumped through the air, there is seldom a question of damaged insulation and the fault must be laid to the arrester circuit. There are at least four leading questions of interest to the engineer.

1. Subject of quantity and frequency. Was the arrester resistance too high?
2. Subject of frequency. Was the equivalent needle-gap too high at the particular natural frequency of the discharge? (Some arresters vary in equivalent needle-gap with a variation in natural frequency of the lightning surge.)
3. Subject of earth connection. Was the resistance of the earth connection abnormally high or was the distance between the earth connection and arrester abnormally long?

4. Subject of resonance. Was there a standing wave with a node at or near the arrester and an anti-node or peak at the point of puncture?

The first three subjects are matters of design. The fourth subject is a matter of the location of arrester and choke-coils. Unless the trouble inspector enters the field with predetermined knowledge of the action of an arrester under the strains of different kinds of lightning strokes, the inspection is fruitless. Such a knowledge can be obtained only through laboratory tests with artificial lightning.

Example of interpretation from inspections. As an example of interpretation from an inspection the following is given. Arresters of special design, set very close to line potential, were installed on a long system operating at 13,000 volts. Near the generating station the arresters were arranged to give less possibility of short-circuit under heavy lightning than in the sub-stations. During the entire winter the line superintendent conscientiously examined and removed tell-tale papers in the arrester gaps. About the only information gained during all this time was that the arresters were sufficiently sensitive to operate from the internal lightning caused by switching and other accidental disturbances. A short time ago a lightning storm occurred. The tell-tale papers at one sub-station showed discharges through the arrester. At another sub-station two current transformers were punctured, but the tell-tale papers in the arresters at the cable terminal house near the sub-station, and in the arresters in the sub-station, itself, showed no discharge. In other words, the discharge passed two sets of lightning-arresters adjusted closely to normal line potential and punctured the two transformers. Why did the arresters fail? What kind of lightning stroke was it?

To answer these questions the predetermined fact is known that these arresters are not sensitive to the first half-cycle of the lightning discharge and therefore not sensitive to low-frequency high-potential surges. When these arresters were installed, the designer knew nothing of the fact nor how to overcome it. It is also known that these arresters are exceedingly sensitive to high-frequency discharges.

A probable explanation is that high-frequency cloud-lightning caused a discharge over the entire arrester, cutting out all resistance. A low-frequency surge followed which passed the other arresters and damaged the current transformers, the weakest insulation in the sub-station. There is one other possible explanation; there may have been a standing wave with the nodes at the arresters. This seems improbable, however, because there were two arresters, and furthermore, the same phenomenon has been observed in several other cases where the insensibility of this type of arrester to low frequency seems to be the fault.

In another paper, the method of correcting the design of the arrester considered above is given. If a manager of a transmission system assumes the untenable position that the manufacturer has sold a piece of apparatus which will not take care of all lightning conditions and is responsible for replacement of arresters, an embarassing commercial situation arises which cuts off free intercourse between the engineers and consequently impedes progress. Perhaps a manager has decided that the arresters are an unnecessary evil and has taken them all off the system. With good luck such a system may run several months without trouble from lightning, but each high-potential surge which enters the station will do a definite amount of irreparable damage to such insulation as is not self-repairing. Sooner or later, enough strokes of high potential occur at one point to cause a puncture, and all other points weakened by overstraining are likely to give way under the secondary strains of the energy surges of dynamic potential coming from the initial short-circuit.

Unless the cause of the failure of the arrester can be traced to something specific, little improvement of design is possible. We have already come to the stage where accurate measurement is the life of further progress. It is necessary to produce artificial lightning of varying potential, quantity, frequency, and duration in the laboratory, and to study with it the characteristic behavior of a lightning-arrester. By applying considerable dynamic energy to the arrester at the same time, the secondary effects of dynamic current discharge and the endurance of the arrester may be determined. Knowing the characteristic behavior of an arrester under varying conditions, it is often possible to make a very plausible surmise of the nature of the cause of the failure. The engineer who advances the argument, as has been done, that " it is only a laboratory test and does not prove the value of the arrester " loses the proper viewpoint. The object of the laboratory test, aside from the educational experience it gives, is to prove the converse condition regarding an arrester; that is to say, if the arrester will not withstand reasonable laboratory tests in conjunction with the insulation which it is designed to protect, it is sure to fail sooner or later on the line. If the laboratory test shows the arrester weak in some particular point, and that point only, it does not necessarily condemn the arrester, for it may be due to a condition which may be taken care of by some other kind of arrester or one that may not occur on the circuit in years. But if such an arrester fails, it often seems permissible to attribute the cause to this weakness. With such knowledge it is possible to employ to great advantage a particular type of arrester on certain kinds of circuits or in certain locations.

An analysis preliminary to standardization recommendations. Before attempting to write standardization rules, it is pertinent to review the necessities of the situation.

First of all is the selection of names for the apparatus and the general terminology as a means of common intercourse.

The second consideration is the nature of the lightning so far as known, and the strain which must be relieved by the protective apparatus.

The third consideration is the nature and characteristics of the insulation to be protected.

The fourth consideration is the characteristics of the protective apparatus.

The fifth consideration is the nature of the test with artificial lightning, which will demonstrate the characteristics of the protective apparatus.

1. TERMINOLOGY

Lightning. Lightning is a general term to express surges of potential anywhere of dangerously abnormal value. The subdivisions of lightning are external and internal. Cloud lightning is external lightning. Dangerous surges due to switching etc., are internal lightning.

Protective apparatus. There is required a general term to cover all devices which give protection. Protective apparatus is suggestive, clear, and brief.

Lightning-arresters. A name is required for devices connected not only between lines but also between lines and ground. So far "lightning-arresters" is the commonly used term, and it seems desirable to retain this to avoid confusion.

Internal-surge protectors. Another device, which may be of the same form as a lightning-arrester, is connected only between line and line, not to ground directly. There are a great many of these devices installed at the present time, and it is desirable to have a convenient special term to distinguish them from lightning-arresters. The term "static protector" has been frequently used. The term is not suggestive of the nature of the device, and may be confused with the apparatus known for a long time as a "static discharger." "Static" means specifically the displacement in a dielectric medium. There are static strains which may be distinguished from one another. There is the normal static strain of potential between line and line which varies every instant with the wave of electromotive force of the generator. There is also the excessive static strain between line and ground due to cloud-lightning strokes. There is still further, the excessive static strain between line and line, due to the stoppage of a dynamic flow of electricity in a number of ways; and there is, finally, the excessive static strain between line and ground, due to the gradually accumulated static electricity from wind, rain, etc., coming in contact with the transmission line. This last form of static will not be released at all by the static protector so there seems to be no reason for standardizing this false nomenclature. Devices for carrying off the gradually accumulated static, usually have low current-carrying strength and have been known for years as "static dischargers." Since this form of static is directly generated in the line, and the word "static" is suggestive of rest, it seems desirable to retain this term "static discharger" for the discharges of gradually accumulated static electricity. Conversely, since the other static stresses are indirectly generated from electromagnetic stresses, and furthermore, since this electrostatic stress is continually being transformed into electromagnetic stress and back again in the form of surges, it seems desirable to adopt a term like "internal-surge protector." It lacks brevity but there is no doubt of its meaning.

A lightning-arrester is always more or less of an internal surge protector according to its design, and it may have auxiliary devices which make a static discharger of it also. On the other hand, an operator should not deceive himself into a sense of security because a static discharger has been sold to him under the misnomer of a lightning-arrester. Again, an operator cannot expect an internal-surge protector to protect against surges of an external origin, as for example, cloud-lightning.

Earths (connections, resistances, etc). The word "earths" is used here specifically to mean the connection between the conductor and the earth in which it is buried. On overhead lines it is usually the only " ground " connection. (See further " grounds.")

Length of the earth connection of an arrester is the distance from the arrester to the conducting stratum of the earth.

The earth resistance of a lightning-arrester is the ohmic resistance from the arrester to the conducting stratum of earth. Its value may be obtained by measurement between three earthed conductors.

Grounds. " Grounds " is a more general term than earths. A phase may become grounded without being earthed; for example, a cable having its armor insulated from the earth may become " grounded " by having one of its conductors connected with the armor. The armor may be " earthed " by connecting it with a conductor buried in conducting earth—in this case, we may still speak of the phase as grounded. If the transmission system is a mixed cable and overhead system, "earthing" the armor may make a considerable change in the surges through the system.

Sparks. An electric spark is the phenomenon of conduction of electricity by a luminous gas.

Arc. An arc is the phenomenon of conduction of electricity by the heated vapor or vapors of the electrode.

Dielectric-spark lag. Is the time elapsing between the application of the sparking potential and the complete formation of a spark.

Natural or proper frequency of a circuit is the number of oscillations per second of potential or current which will take place if the circuit is allowed to discharge without interference from excessive damping or extraneous power. Such a circuit involves the presence of both capacity and inductance.

Continuous and continual, as applied to the electrical terms, retain their defined sense. A continuous oscillation is one which appears without a break. Continual oscillations are successive sets of oscillations with more or less interval between the sets. A generator furnishes continuous alternations, a Tesla transformer produces continual oscillations. Continuous lightning is sometimes produced by one phase of a generator when another phase is short-circuited. Continual lightning is produced on a non-grounded neutral system when one phase is connected to ground through an arc. Both continuous and continual lightning may be temporary, but should be distinguished from transitory lightning.

Recurrent surges is a term synonymous with continual surges.

Surges. Electrical surges is a term having a sense a little more general than lightning. Any unusual rush of current or potential is a surge. If the surge potential reaches a dangerous value it is lightning.

Transitory. Transitory, as applied to electrical terms, retains its defined sense. Cloud-lightning gives transitory lightning on a transmission line. Many lightning-arresters are designed for transitory lightning but not for continual lightning.

Equivalent spark-gap. This is a general term to express the puncture potential equivalent of a piece of apparatus or insulation. The gap is in parallel with the device and of such value as to cause at least 90% of the spark discharges to pass through the device and not more than 10% across the gap. The equivalent spark-gap is the only means of directly indicating the potential of a transitory charge. The specific terms are equivalent needle-gap and equivalent sphere-gap.

Equivalent needle-gap. Is the gap of the value explained above when the electrodes of the gap are needles.

Equivalent sphere-gap. Is the gap of the value explained above when the electrodes are spheres. It is necessary to state the diameter of the spheres—for example, equivalent 2-inch sphere-gap.

Equivalent spark-gap characteristic curve. This is the relation of the applied potentials as represented by gap-lengths (abscissas) to the equivalent spark-gap (ordinates). In this expression the specific words " needle " or " sphere " may be substituted for " spark."

Dynamic. Used as an adjective to the words current, voltage, wattage, energy, etc., designates the current, voltage etc., which come directly from the dynamos or generators, as distinguished from the current, voltage, etc., which come from static charges, electromagnetism, cloud-lightning, etc. on a line. The latter is of relatively small energy. There is no general term to express all the discharges that are not dynamic. "Static" is a word used in this sense a number of times, " lightning " is another; but they are both specific and not general. For example, the internal lightning from one phase of a generator when another phase is short-circuited is really dynamic potential, dynamic current, dynamic energy, etc. It is true that before a discharge takes place there is always a storage of energy in the static stress, in spite of the fact that the source of this static stress may have been due to the aforementioned condition, or to the sudden interruption of a dynamic current, and therefore, static comes the nearest to expressing the general sense. Non-dynamic would be a general adjective covering the phenomena not directly derived from the generator.

Static. This term was originally applied to the stationary charges of electricity on rubbed glass, wax, etc. The use of the term has been extended until it covers all forms of electric displacement in a dielectric. This electric displacement may be changing its value at every instant and the electric charge is therefore not stationary. The variation in dielectric displacement gives the static current or condenser current.

Non-dynamic. Is an adjective applied to the electrical terms to cover all effects which do not have their source directly in the generators.

Accumulated static charge. This term applies to the charges of electricity which accumulate on a transmission line due to wind, rain, etc. and represents an electric displacement in the dielectric between line and earth.

End-gap static. Discharges of a multigap arrester. On high-potential circuits a few of the series gaps at each line connection are bridged by tiny sparks which give out a buzzing sound. The number of gaps bridged by the sparks depends on several factors—applied potential, relative capacity of each cylinder to its adjacent cylinder and ground, and leakage through or over the surface of the supporting porcelain.

Grounded neutral system, and *non-grounded neutral system* as applied to a transmission circuit are terms which are self-explanatory. A three-phase delta circuit may have an artificial neutral made by the connection of auxiliary apparatus in *Y* relation, and this neutral may be grounded. The word neutral cannot be omitted in this expression without confusion with the continual lightning condition of an accidentally grounded phase.

Forced oscillations. Forced electrical oscillations are oscillations impressed on a circuit regardless of the free, natural, or proper oscillations of the circuit. Alternations from a generator on a line are forced alternations.

Resonance. If the forced oscillations have the same frequency as the natural oscillations of the circuit there is perfect resonance, or tuning, and both the current and potential will assume abnormal values.

Standing wave. A standing wave is to be distinguished from a traveling wave. A standing wave is caused by traveling waves moving in opposite directions and so timed that they pass each other always in the same relative position. The result will be nodes at certain points and anti-nodes at points midway between. The nodes remain at zero or normal potential, and the anti-nodes vary in potential from double the potential of a single wave in the positive sense to the same potential value in the negative sense.

Rate of discharge is the current, $I = \frac{dQ}{dt}$. The rate of discharge is an important factor in connection with the resistance of a lightning-arrester.

Acceleration of discharge is the rate of change of current. Acceleration $= \frac{dI}{dt} = \frac{d^2Q}{dt^2} = \frac{E}{L}$. The acceleration of discharge is an important factor in connection with the inductance of a lightning-arrester circuit.

Recurrence. Recurrence is a convenient word to use to avoid confusion with the word frequency in a technical sense. The frequency (natural) of lightning may be about a million cycles per second, but the frequency of recurrence of lightning stroke may be expressed in minutes or months.

Oscillogram. The tracings of wave-forms taken with an oscillograph.

Multigap. Multigap expresses the condition of a number of gaps between conductors in series.

Multipath. Multipath expresses the condition of a number of gaps or circuits in parallel.

Multiplex connection. On a lightning-arrester, this commercial term means that there are certain cross-connections between phases of the arrester above the earth connection. These cross-connections may or may not have an appreciable resistance.

No-gap aluminum arrester. An aluminum arrester composed of a series of aluminum electrolytic cells connected directly to the lines without the intervention of any gaps.

Gap aluminum arrester. Is the same as above except there is a gap between each phase wire and the cells to prevent the natural capacity current of the cell from flowing continuously.

Graded resistance arrester. A trade term to express the form of multigap arrester according to the 1907 design. A number of resistance circuits of variable ohmic value are thrown in parallel across the simple multigaps. These resistance circuits have a common connection at one end and tap in at different points on the multigaps.

Nature of lightning. In the A. I. E. E. PROCEEDINGS, May, 1906, the writer gave a brief outline of lightning effects as a basis for a laboratory study of methods of measurements. Dr. C. P. Steinmetz has given a very complete classification of lightning on transmission lines* from the broad standpoint of the analyst of the phenomena. While it is necessary to keep in mind the classification according to the phenomena, it is more direct for the designer of protective apparatus to analyze according to the effect of the lightning on the insulation and the lightning-arresters. Regardless of the cause of the lightning, the arrester and insulation take into account in the two kinds of lightning, transitory and continual, only the three factors—the frequency, the duration, and the potential of the stroke.

The nature of lightning on electrical transmission has been very little studied by direct measurements, on account of the lack of specific instruments with which to make the measurements, the erratic appearance, the transitory duration, and the danger involved.

Frequency. By a study of artificial lightning it can be demonstrated that a transmission line may be subjected to any frequency of electrical oscillation ranging from one-half cycle per hour (gradually accumulated static electricity) to about a billion cycles per second. On many particular lines the frequencies of oscillations will exist probably in groups of harmonics. The first and lowest group starts with the generator frequency and runs up in odd multiples thereof to all the higher harmonics. On account of the impossibility of getting very abrupt changes of magnetism in a generator (due to the relative permeability of iron and air) the upper harmonics from the generator wave very quickly become negligible.

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*PROCEEDINGS of A. I. E. E., March 1907.

It is usual to assume that the fundamental wave of the generator will not attain an abnormally dangerous value on account of the limitation of the exciter voltage, but under the special condition of a short-circuited phase on a multiphase generator, the voltage of the phases not short-circuited may rise to a very dangerous value. Several years ago Mr. L. Robinson, at the suggestion of Dr. C. P. Steinmetz, took oscillograms of this condition of operation in some large generators and found a rise of 250%. This surge requires special attention in the application of lightning-arresters.

The second group of oscillations starts with the natural period of the electrical circuit, including in its factors the inductance and capacity (static) of transformers, cables, overhead lines, choke-coils, and translating devices of any kind in the common circuit. There are also the upper harmonics of this group. The first group may overlap the second group. If any frequency of the first group coincides with that of the second group, then that particular oscillation of the second group is in resonance (or in tune) with the particular wave of the first group, and its free oscillation will be magnified until the natural energy losses of the oscillation are equal to the energy derived from the harmonic of the generator wave.

The third group of oscillations includes those starting with the fundamental frequency of the transmission line or cable (not including the apparatus.) The line or cable may oscillate as one segment or any odd multiple thereof, giving thereby all the upper harmonics.

The fourth group of oscillations may be designated as miscellaneous. In this group will fall such oscillations as those between the system and an isolated conductor. An example of this kind of oscillation is found in the multigap arrester. Usually about a half-dozen gaps next to the line connection will have a spark-discharge across them continually. Each time the second cylinder is connected to the first, an oscillation is set up on the line, the results of which have been experimentally measured.

The fifth group of oscillations comes from external sources and will oscillate independently of the line. In this group are the forced oscillations on the line derived from cloud-lightning.

The natural frequency of cloud-lightning, not yet having been measured, is presumably determined by the static capacity of the part of the cloud that is discharged and the inductance of the discharge path between cloud and earth. Since both the inductance and capacity vary, the natural frequency of the cloud-lightning will also vary over a limited range. In this group come also the oscillations on a line from wireless telegraphic signals and induction from adjacent transmission lines. If any of the oscillations of the previous groups are in tune or resonance with one of the fifth group, then such an oscillation may be enormously magnified. It is useless to speculate on whether or not cloud-lightning has any upper harmonics.

Following is a summary of the five groups.

First group. Generator frequency and harmonics.

Second group. Natural frequency of the main circuit and harmonics.

Third group. Natural frequency of the line circuit and harmonics.

Fourth group. Miscellaneous oscillations.

Fifth Group. Forced oscillations from an external source.

Comments on the five groups. The generator and cloud-lightning are both sources of energy. The generator frequency is below any of the natural periods of the lines and therefore its fundamental wave is impressed on the line from end to end with only relatively slight modifications of form by inductance and capacity; the cloud-lightning frequency is unknown, but there is reason to believe that it may be of the order of 100,000 to 1,000,000 and will consequently agree with some of the possible oscillations of the other groups. The oscillations on a line due to cloud-lightning are of a double nature; there are first the forced oscillations due to the natural frequency of the cloud discharge, and second the free oscillations of the charge left on the line.

1. These forced oscillations may be more or less magnified or nullified by interference. Unlike the generator forced wave, the cloud-lightning forced wave may be far above the natural frequency of the line, and the whole line cannot rise and fall simultaneously with the cloud-lightning oscillations. There will be a succession of waves which will be partly reflected from the ends of the lines, and the reflected wave traveling in the opposite direction will combine algebraically with the waves it meets. If the line is an odd multiple of

a quarter wave-length, two waves traveling in the opposite direction will meet at a certain point on the line and will neutralize each other; the succeeding wave will do the same at the same point; consequently this point of the line will remain at constant potential. At a quarter wave-length in either direction on the line, the potential is changing its value at every instant as the waves cross each other. The result is that the potential will vary gradually and harmonically from zero to twice the original height of the traveling wave. This effect has been called a standing wave. It is variable in value of potential at every instant, but is fixed in its position on the line. Three positions of such a wave are illustrated in Fig. 1. *A* and *B* are two points on the transmission line. The dotted curve represents the reflected wave, and the broken curve the standing wave. The point *A* is zero for all positions of the waves and is therefore the node. The point *B* is zero in the top curves, 150% in the middle curves, and 200% of the traveling wave in the lower curve.

If the length of the line is not an odd multiple of the quarter wave-length then the reflected waves cause a jumble without definite form.

If the induction from the clouds is electromagnetic (horizontal lightning stroke parallel to the line) there is no resultant quantity of electricity on the line and the surges set up will die out gradually by loss of the initially imparted energy; but if the induction from the cloud is electrostatic there will be a definite charge of electricity set free and left on the line.

2. The free oscillation. When a thunder-cloud over a line discharges, it may set free a charge distributed over the line according to the area of the liberated charge on the cloud and its position relative to the line. The length of charged line may be perhaps of the order of 1000 ft. to 5000 ft. If the line had sufficiently high resistance, this charge, when liberated, would spread over the line as a bucket of water flows when thrown into an empty trough. The line resistance in reality is almost negligible, consequently the energy of the charge will be transformed into electromagnetic energy and back, continuing to oscillate until the waves are damped out. Neglecting leakage to ground, this charge will finally have changed its position from the occupancy of the capacity of a short length of the line, to the occupancy of the total capacity of the line, and in consequence its potential will have decreased proportionally. Mean-

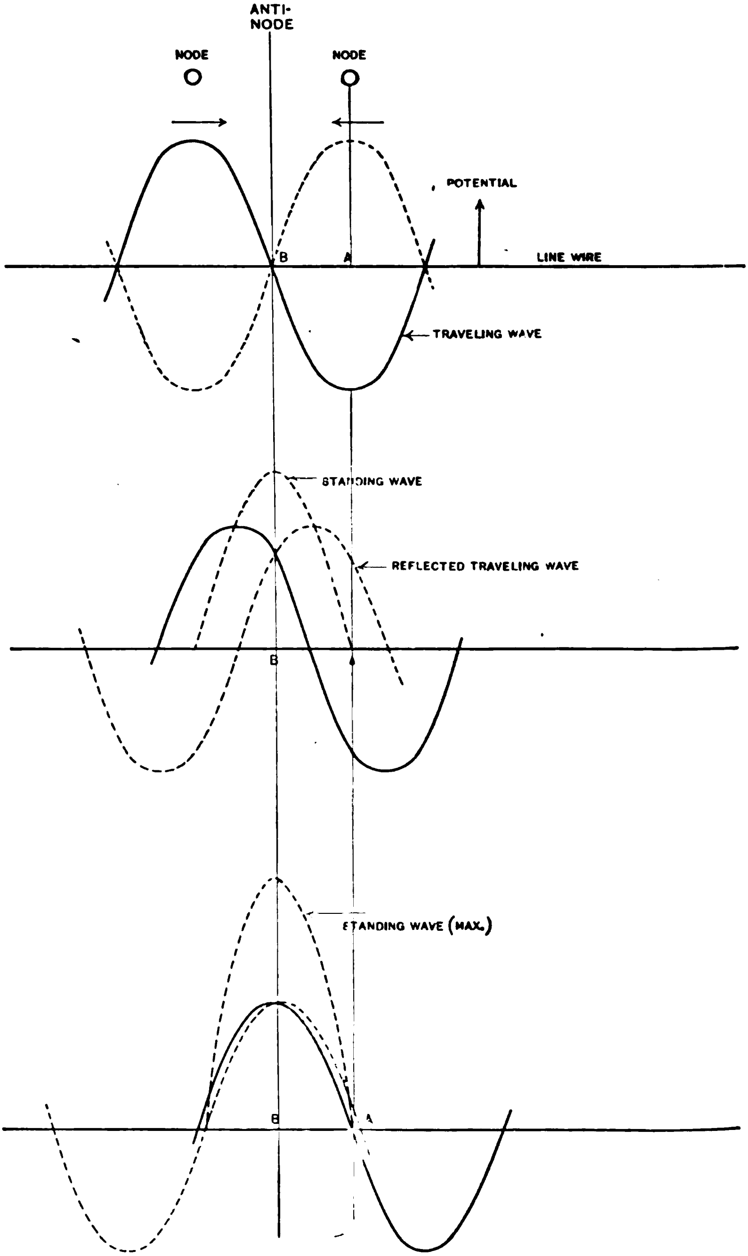
ANTI-
NODE
NODE
NODE
POTENTIAL
B
A
LINE WIRE
TRAVELING WAVE
STANDING WAVE
REFLECTED TRAVELING WAVE
B
STANDING WAVE (MAX.)
B
A

Fig. 1

while the waves have traveled in both directions on the line, giving the possibility of a standing wave.

We can examine the condition giving a standing wave by assuming a fictitious line 100,000 ft. long and the length of the line covered by the induced charge at 2000 ft. The quarter wave-length then is 1000 ft. If the line is divided into imaginary 1000-ft. sections, and if the liberated charge should so occur as to cover exactly two of these sections, the reflected waves would be so timed as to cause standing waves. If the charge were liberated in any fractional position of the 1000-ft. section the standing wave would be more or less destroyed.

Following out this line of reasoning, it is evident that a standing wave is a matter of chance not only in the relative location of the liberated charge on the line, but also in the relative length of the charge to the length of the line. If this theory is true, strokes of equal potential may vary greatly in their resultant effects.

There is an important condition of surge, involving probably all the first three groups mentioned above. This has been mentioned elsewhere as the grounded-phase condition. In this the generator is the source of energy, but it does not force the oscillation into the system. Owing to the grounded-phase condition of capacity, the generator produces a static charge which is set free to vibrate by the making and breaking of the arc between the faulty phase and ground. The phenomenon is somewhat analogous to putting a spring under tension and suddenly releasing it. As with the spring, the electrical oscillations die out, but may be renewed a number of times during a half-cycle of the generating wave. An oscillogram of this condition is shown in Figs. *P*, *S*, and *T*, " Methods of Testing Protective Apparatus," Proceedings, American Institute of Electrical Engineers, May, 1906.

Duration of lightning. Nearly all lightning oscillations are individually of short duration. There is one notable exception; namely, the continuous surges set up on one line from a parallel line (*e. g.* telephone circuit under a power circuit). All the transitory surges have a logarithmic decrement of potential and current. The rate of decrease of the peaks of the lightning potential depends upon well-known laws; it is proportional to the rate of dissipation of the energy of the stroke. The energy of this electrical charge is dissipated in at least three ways; radiation, heat, and chemical transformations.

Hertz has shown that an open circuit is a good radiator of energy (wireless telegraphic waves) and therefore a poor oscillator. On the contrary, a closed circuit is a poor radiator, but it will oscillate for probably several hundred cycles, provided the energy is not absorbed in resistance and arcs in the circuit. Hertzian waves are radiated only at extremely high frequencies. Lower frequencies radiate in the form of brush discharge only. There is an analogy to the hertzian waves in sound vibration. If the air is not struck with a quick blow, it slips around the vibrating material and does not send out a sound wave. A transmission circuit may oscillate as either a closed circuit or an open circuit. Line-to-line oscillations are examples of the former; line-to-ground oscillations of the latter.

The line wires, as closed circuit oscillators, have a very low ohmic resistance and therefore, as far as this factor is concerned, a small decrement of voltage. If the oscillation is low enough in frequency to pass through transformers, the hysteresis and eddy losses in the iron will very quickly destroy the free oscillations. In each of these cases the energy of the electrical discharge is transformed into heat.

In arcs, especially the liquid-electrode types, and when the oscillating current is passed through electrolytes, such as the aluminum-cell type, more or less energy is absorbed in chemical dissociation.

Decrement. What is the best value of decrement? This question is open to discussion. The shorter the duration of the oscillation, the less will be the liability of damage to the insulation; or the quicker the lightning-arrester operates after the potential rises, the less the likelihood of damage to the insulation.

Without going into mathematical refinements, the duration of lightning, as affected by logarithmic decrement, can be demonstrated by simple curves. The subject of oscillating current is thoroughly treated in a number of text-books, but there are certain specific conditions concerning lightning which make some of the general statements regarding the surges inapplicable to lightning on transmission lines. As an example, the general statement is made that with a fixed inductance, capacity, and quantity of electricity, the time of quickest discharge exists when the value of resistance in series is equal to the critical value $R = \sqrt{\frac{4L}{C}}$. This is not true for lightning on a transmission line without lightning-arresters, and it is further from the truth for the lightning-arrester circuit itself. The duration of lightning on a transmission line without arresters will be shorter if the resistance (or its equivalent in other energy-absorbing power, as brush-discharge, electrochemical energy, etc.) is less than the critical value. The arrester is placed directly in shunt with the transmission apparatus, and although the surges on the line may continue for a longer time with negligible resistance in the arrester, the potential across the arrester is reduced quickly to a safe value in spite of the longer duration of current. The duration of lightning is the time required for the potential to reduce to the safe value. The relations are shown graphically in Figs 2, 3 and 4. Fig. 2 shows two curves of a potential discharge when the only variable is the initial lightning potential. The resistance has a value above the critical value. The higher the initial lightning potential in this case, the longer will be the duration of the lightning. This corresponds to the discharge of lightning through an arrester or static discharger containing high series resistance. Fig. 3 shows two discharges, one non-oscillatory and the other oscillatory; for simplicity these are given the same decrement. The resistance in the case of the oscillatory discharge is less than the critical value, and the duration of lightning is about the same as for the value of resistance above the critical value.

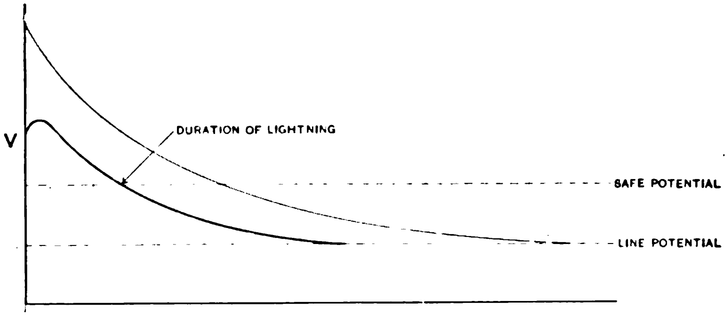

Fig. 2

Fig. 4 shows the condition of most rapid discharge of lightning. The resistance lies between the two values of Fig. 3, but the rate of energy-loss is greater. The second half-cycle brings the potential to the safe value. If the energy is absorbed in electrochemical action, as in the aluminum cell, the energy loss is proportional to the quantity of electricity, and the resistance may be zero without affecting the result. Furthermore, the critical lightning potential of the aluminum and liquid-electrode arresters will prevent the potential from rising above the safe value on the first half-wave. To obtain the same result at the multigap arrester terminals it must be possible to cut out all series resistance if the viciousness of the discharge demands it. The above discussion is made without reference to the dielectric spark-lag.

Continual lightning. Recurrent surges. Although each lightning surge is transient, in general there may be a succession of free oscillations with normal value of potential between them.

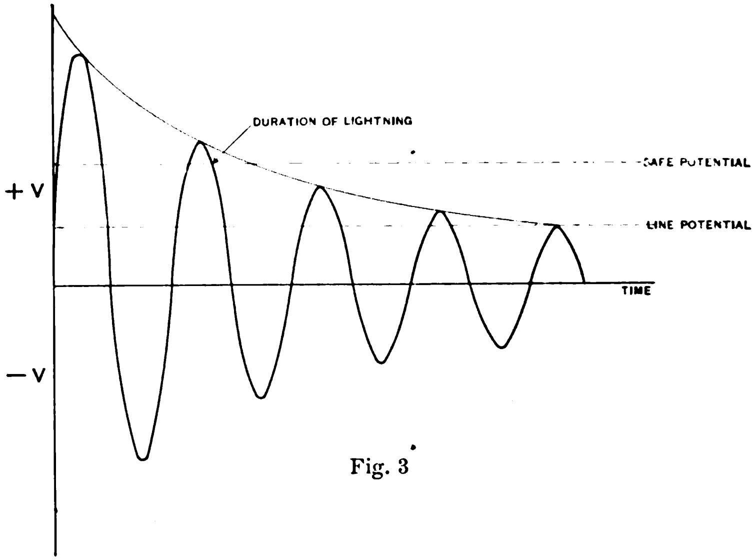

Fig. 3

These recurrent surges result invariably; for example, from a grounded phase on an insulated Y or delta system and from a loose contact on an alternating-current trolley system. As a rule, the duration of each surge cannot even be guessed at, but the total duration of the successive surges is limited only by the removal of the condition which caused them.

Potential of the surge. This subject is best treated under the two heads of transitory oscillations and continuous oscillations.

In the case of free or natural oscillations there is always a loss of energy and a consequent decrement in the successive peaks of potential. The only method of measuring potential in this case is by the equivalent spark-gap. If the oscillations are sufficiently low so that a quarter-cycle is not greater than the dielectric spark-lag of the gap, the gap may be expected to be proportional to the potential. On the other hand, if the frequency is exceedingly high, or the drop of potential is rapid, then the gap will no longer measure the peak value of potential, but some lesser value of potential depending on the two factors, spark-lag and logarithmic decrement of discharge. An illustration of this was given in a paper by the writer, (PROCEEDINGS of the American Institute of Electrical Engineers, May 1906.) As a result of this condition the maximum potential cannot be determined and the nearest expression is to state the equivalent spark-gap. This dielectric spark-lag, with some types of apparatus, has a bearing on the problem of protection. The insulation to be protected has also a dielectric spark-lag, and while it may not puncture before the arrester releases the strain, it may nevertheless receive an injurious blow. If the insulation has the property of "self-repairing" the injury is transient.

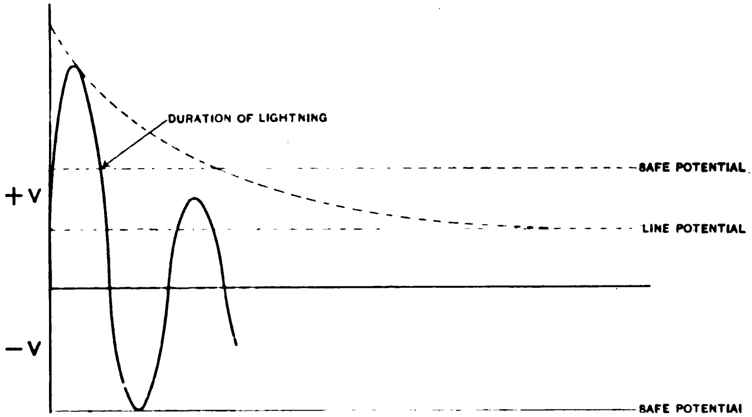

Fig. 4

Continuous oscillations must be distinguished from recurrent oscillations. The needle-gap in parallel will apparently measure the potential in this case, but, continuous oscillations occur very seldom in lightning-arrester work. If recurrent surges follow each other in very rapid succession, it seems reasonable to assume that the equivalent needle-gap is a close measure of the potential, but this condition of "very rapid succession " is too indefinite to be relied upon. In consequence we shall necessarily be limited in this case also to expressing the potential, not in volts, but in equivalent spark-gap.

3. *Nature and characteristics of the insulation to be protected.* Tests of dielectric strength have been made for years on insulations with continuously applied potentials, applications ranging in time from one second up. Much of this information is available in published form. Tests of insulation with transiently applied potentials are meager.

Under transiently applied potentials the three types of insulation—solid, liquid, and gaseous—have properties not shown by the tests of continuously applied potential. This difference results from both the dielectric spark-lag and the property of self-repair. Solid, liquid, and gaseous insulations differ in degree in these two characteristics. When the disruptive potential applied to the oil insulation is removed, the injury inflicted is gradually repaired, provided a slight circulation at least of the oil is possible. Oil has also a comparatively high dielectric spark-lag. Air has the property of self-repair, but its dielectric spark-lag is much less than that of oil. Solids, in general, have no self-repairing property but have a dielectric spark-lag lying between the values for liquids and gases. The characteristics of any insulation are studied by the same methods as lightning-arresters. These methods are given farther on.

The spots most vulnerable to lightning in electrical apparatus are the bushings to the leads, the end-turns, and the space between phases. Briefly stated, there are just two factors concerning lightning and insulation that should be known; namely, the potential, and the duration of its application at abnormal values.

4. *Characteristics of lightning-arresters.* After what has preceded, the qualities which an arrester must possess to protect insulation are fairly evident. The questions to be answered are:

A. Is the equivalent needle-gap affected by the natural frequency of the oscillation?

B. By the rate and acceleration of discharge?

C. By the quantity of discharge?

D. What is the nature of the dynamic current suppressing device?

E. What is the endurance { to single strokes? / to recurrent surges?

F. Is there a dielectric spark-lag?

Before attempting to answer these questions by the designation of tests, a review is made of the simpler tests described by the writer in the PROCEEDINGS of the American Institute of Electrical Engineers, May 1906. To these tests some additions have been made.

First test. Test of static discharger. This test is of less importance than those following. The source of energy in Fig. 5 is a static machine. The equivalent spark-gap is the value of the gap *G* which causes the discharge to pass through the arrester. The spark-gap is necessarily a sphere-gap because the needle-gap will carry off the current of a small static machine in brush-discharge as rapidly as it is generated, and thus limit the potential to a small value. The condensers are sometimes used as a convenience in observing the spark-distance. The report from the condenser-discharge cannot be confused with any brush-discharge.

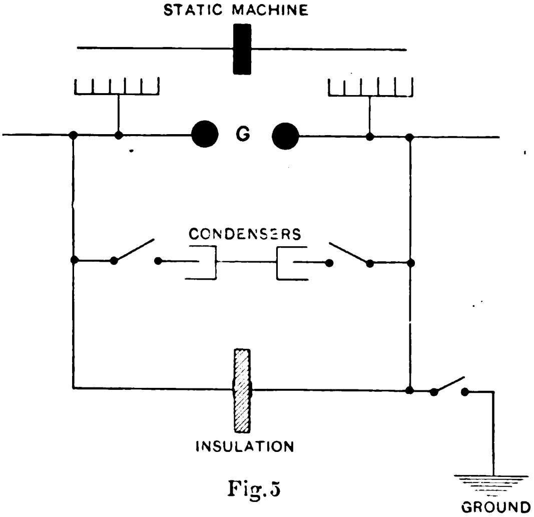

Fig. 5

If the static-discharge has a high frequency, the measurement of the ohmic resistance will permit a calculation of the current flow at double the normal potential of the system. Double potential is here chosen, as in other similar cases to follow, with a specific object in view. For the present at least, it seems necessary to design the insulation of electrical apparatus with a minimum factor of safety of 2. Therefore 200% gives the discharge current at the limiting value of potential. There is a more important reason for choosing 200% potential for the calculations. Some types of arresters, especially the electrolytic types, have a small current discharge at normal potentials, but have a critical value of limiting potential above which the current flows freely. Choosing 200% normal potential for the purpose of calculation brings out the desirable characteristics of these arresters.

Second test. Equivalent needle-gap at commercial frequency by step-up transformer. Fig. 6 shows the recommended connections of the transformer, arrester, and needle-gap. The presence of

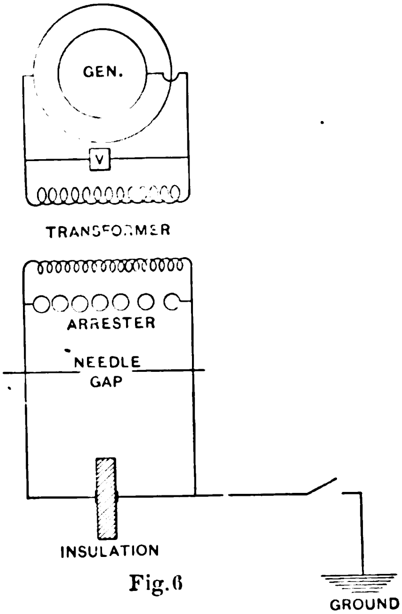

Fig. 6

insulation is not necessary, although it is sometimes desirable. The thickness and nature of the insulation, when used, is the same as the arrester is designed to protect.

Two equivalent needle-gaps differing somewhat in value are obtained from this test. They are:

a. Equivalent needle-gap (E.N.G.) by transformation.
b. Equivalent needle-gap (E.N.G.) by needle-gap.

The equivalent needle-gap by transformation gives the potential of the fundamental wave, and the value by needle-gap gives approximately the peak of the superposed surges derived from the various local oscillations of the high-potential circuit.

There are three tests to be made, making six equivalent needle-gaps in all.

First, condition, no grounded phase; switch *S* open.

Second, condition, grounded phase; switch *S* closed.

Third, condition, arcing ground, switch *S* arcing to maximum length of arc.

Third test. Disruptive-stroke test. There are two simple forms of circuits which are recommended for this test. The principal difference between the two, lies in the use of a static machine as a source of potential in one case, and a transformer in the other; see Figs. 7 and 8.

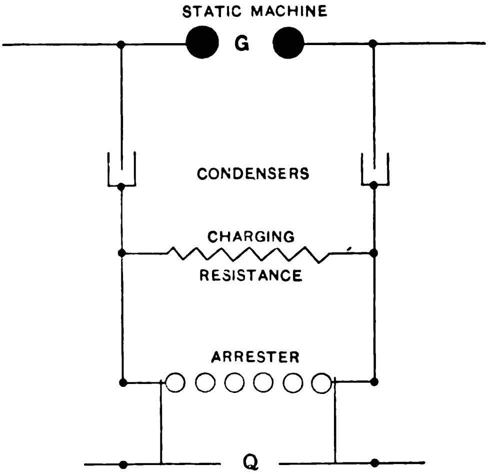

Fig. 7

In Fig. 7 the potential corresponding to the gap *G* is apparently the same as the spark potential obtained from tests with a transformer, and not the values corresponding to the direct-current potential.

Fig. 8 is a modification of the circuit used by Mr. Percy Thomas a number of years ago for starting the dynamic current across the arresters. The modification results from the different desideratum. The quantity sought is the equivalent spark-gap. It was found that the two gaps corresponding to the gap *G* and insulating the arrester from the transformer until the spark jumped both gaps, caused variations in the equivalent spark-gap, according to the relative lengths of the two gaps. Some details of the tests which led to the adoption of this simpler circuit (Fig. 8) are given elsewhere in this paper.

Method of disruptive stroke test with the static machine as source, Fig. 7.

Choose a charging resistance of the order of a megohm and state its value if known.

Before connecting the arrester to the circuit, make the equivalent spark-gap characteristic-curve of the charging resistance. This curve shows the limitations of the testing apparatus.

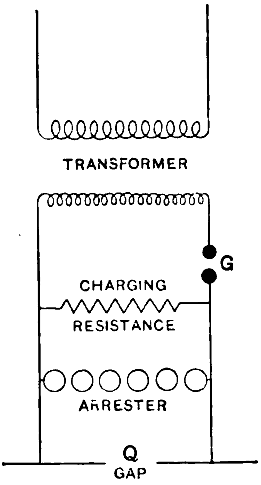

Fig. 8

The abscissas of this curve are the lengths of the setting of the gap *G*, and the ordinates are the corresponding values of the needle-gap or sphere-gap *Q*, which will allow not more than one in ten of the strokes at *G* to pass over the *Q* gap. This curve once made, is good for all subsequent tests.

Place the arrester in position, and take the equivalent spark-gap-characteristic-curve in the same way as for the charging resistance.

The value of capacity to use in this test need not be standardized. There is a certain minimum value of capacity which gives a discharge of sufficient energy to puncture the insulation which the arrester was designed to protect. The maximum value of capacity which may be used is determined entirely by the size of the static machine. When the leakage through the condenser equals the current generated by the static machine it becomes impossible to raise the potential across the gap *G* to the spark value. For most of the tests the writer has found four one-gallon Leyden jars (two on each side) sufficient, and an upper limit of the gap *G* of 5 to 7 in. This apparatus will send a spark over about 200 of the 1/32 in. multigaps under the usual conditions of installation, and the number of multigaps may be greatly increased by using antennae wires near the row of gaps.

The terminals of the spark-gap *Q* should invariably be connected to the terminals of the arrester. The natural frequency of the oscillation will be of the order of a million, and consequently a few inches of wire added to the arrester length will, in many cases, add very materially to the value of the equivalent spark-gap.

There are a number of variations of the circuit of Fig. 7 which have been used in research work, but such variations would complicate the methods of test without a corresponding gain in the knowledge of the operation of the arrester. Some of the results of these variations are given elsewhere by the writer. The variations consist in making such changes as replacing the charging resistance by a charging reactance of a high value, and the introduction of reactance-coils in the circuit at different points.

Method of disruptive-stroke test with a transformer as source of potential. Fig. 8. The figure makes a description unnecessary. The same charging resistance and condensers may be used, and also the same gap *G* in the new location.

The procedure is to set the gap *G*, and then increase the excitation of the generator (preferably of smooth wave-form) until *G* sparks and opens an automatic circuit-breaker. The excitation should then be slightly increased to overcome the effect of the dielectric spark-lag which gives a gradual breakdown of the air in the gaps when the voltage barely reaches the spark voltage. The excitation-circuit, resistance, and voltage are then held constant. The excitation-switch is then opened until the circuit-breaker is closed and then closed again—and so on for each discharge.

The equivalent spark-gap-characteristic-curve is made in this case as in the preceding one. The other precautions are the same.

The upper limit of the capacity of the condensers which may be used, is determined solely by the size of the generating apparatus. The capacity of the condensers should be stated in the report.

The two methods using the same condensers, charging resistance, and values of *G* gap give somewhat different values of equivalent spark-gap. The method of Fig. 5, using the transformers gives the higher value. A plausible explanation of this may be found in the ionization of the needle-gap by the applied potential previous to the passage of the spark across the gap *G*. This does not occur in the circuit shown in Fig. 7. Since the spark at the gap *G* (Fig. 8) always takes place at peak values, the gap *Q* is always ionized, whereas in transmission practice the generator potential may be at zero potential when the lightning stroke occurs. This feature is unfavorable to the use of the method of test, but the employment of a transformer with its greater energy capacity and availability will often offset the disadvantage. On the other hand, the equivalent needle-gap

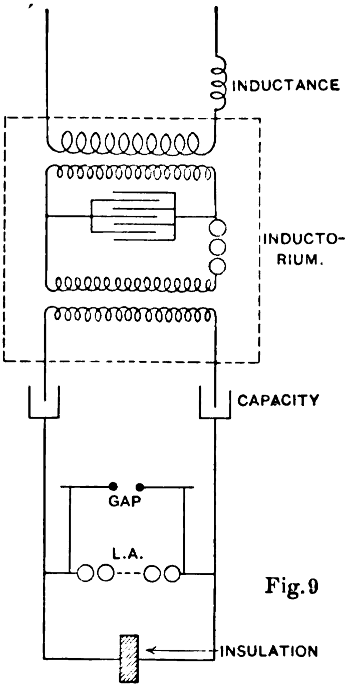

Fig. 9

so found will be at its highest value, since the needle-gap when it sparks, is ionized to a lightning potential corresponding to at least two or three times the normal line potential of the arrester. The arrester gaps are also somewhat ionized by the potential,

Fourth test. The Tesla transformer test, Fig. 9.

The natural frequency of this oscillation transformer is usually of the order of 100,000 cycles per second and the continual discharges are good imitations of continual lightning or resonant surges.

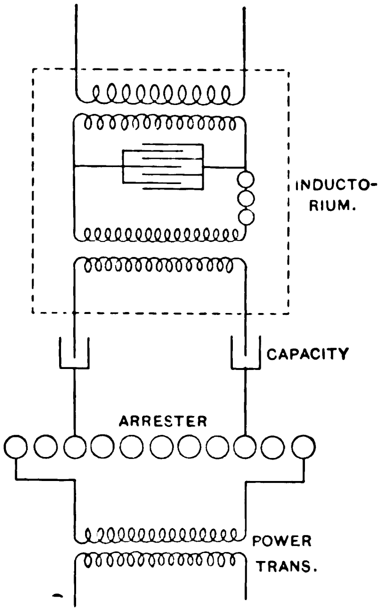

Fig. 10

If it is desired to measure the equivalent sphere-gap by this method, the connections of Fig. 9 seem to be the most desirable. The procedure is to close the switch S and then elongate the gap at G until the arrester takes all the discharge. A needle-gap cannot very well be used at G, on account of the energy lost in brush-discharge from the points.

The Tesla transformer is specially adapted to give the effect of continual lightning. The method of connection to the dynamic circuit is shown in Fig. 10. Condensers are used between the Tesla transformer and the arrester to prevent the short-circuiting of the dynamic-current through the high-potential coil of the transformer. The high frequency passes through these condensers as easily as through a straight wire, but the current at generator frequency is comparatively insignificant. The discharge circuit is arranged so that the current passes in opposite directions, thus lessening the tendency to choose the path through the power transformer. This tendency is still further minimized by connecting the condensers to points on the arrester somewhat away from the ends. These points of connection are determined by trial, the desideratum being to get a uniform continual discharge through the entire arrester.

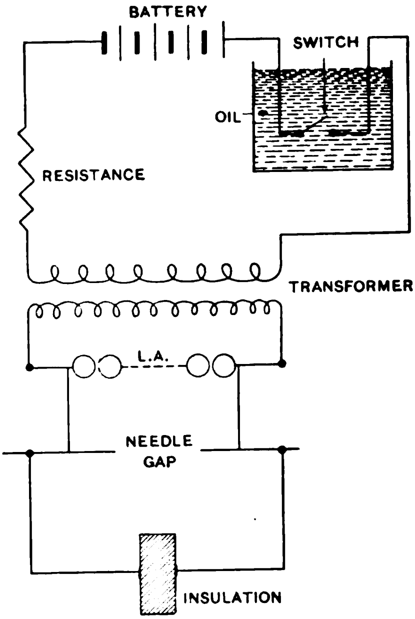

Fig. 11

Fifth test. Half-wave test (Fig. 11). This test for equivalent spark-gap is of great importance as it brings out the sensitiveness of the arrester to the first impulse. An " induction-coil " gives the same kind of discharge in rapid succession and may be used up to the limit of its capacity, instead of the power transformer of Fig. 11. The energy in the induction-coil is limited to a small value, and the observer must assure himself that the energy is sufficient to give the correct value of equivalent spark-gap. The variations of equivalent spark-gap are demonstrated in the tests given in the appendix of this paper, and are made evident by varying the value of direct current in the primary.

In making this test the record should contain statements of the kilowatt capacity of the transformer, the ratio of transformation, and the nature of the primary circuit (battery or dynamo and the total resistance of the primary circuit). Care should be taken to hold the switch in the primary closed long enough to allow the direct current to rise to its full value.

If a spark occurs at the needle-gap on " make " a flaring arc is formed, which with the 50-kw transformer has sufficient energy to melt the points of the needles. The " break " gives a higher potential and forms only a spark; consequently it is more convenient to use.

Equivalent spark-gap of resistances and closed-circuit apparatus cannot in general be obtained by this method, since the presence of such a closed connection on the secondary prevents the rise of potential to high values.

Sixth test. Endurance test. The endurance of an arrester depends on the nature of the dynamic current-suppressing device. There are two factors concerning this device to be determined. The first is the action due to transitory lightning. What is the nature of the suppressing device; the time required to suppress the dynamic, and the maximum current discharge?

The second factor is the action due to continual lightning when the current-suppressing device is brought into continual action. Is this suppressing ability diminished by the passage of the dynamic current?

Oscillograms of the current and voltage during discharge will give, with most types of arrester, enough information to make a fair answer to the questions of the previous paragraph. The oscillograms will show:

a. The duration of the dynamic current and the point of extinction when the instant of starting the current is varied.

b. The voltage across diffeient parts of the arrester.

c. The maximum value of current of the test.

d. If the arrester did not drop the potential of the circuit, a generator of infinite kilowatt capacity could not have done more. If the arrester did drop the potential of the circuit, oscillograms will show where the potential was absorbed, and variations of the current of the test will show the law of relation of current to impressed voltage. From this information the current flow for any size of generator may be determined. If the arrester is designed for transitory lightning only, the endurance is determined by sending discharges at intervals of 10 to 20 seconds until the arrester is seriously damaged or inoperative.

If the arrester is designed for continual lightning, the endurance is determined by sending a continual discharge from some auxiliary device, like the Tesla transformer, over the arrester until serious damage to the arrester or short-circuit to the apparatus results.

An attempt is made below to outline the methods of test which will give answer to the questions at the beginning of the section marked " 4th consideration."

A. Natural frequency. The effect of a variation in the natural frequency of the oscillation on the equivalent needle-gap may be demonstrated, in general, by a comparison of the values obtained from tests numbers 1, 2, 3, and 5. The first test with high-potential direct-current is not always available. Static machines furnish a very small current; the leak over most arresters is sufficient to absorb the charge on the static-machine plates as rapidly as it is generated, and consequently prevents the rise of potential across the terminals of the machine. A sphere-gap must be used instead of the needle-gap, on account of the line discharge from the latter. Where mercury rectifiers are obtainable, high-potential direct-current may be obtained in greater values. This test is usually not necessary as the second, third and fifth tests give sufficient data, as a rule, to demonstrate the characteristics of the arrester. Applications of potentials at alternator frequencies of 16 to 60 cycles (test No. 2) give the actual spark potential both by transformation and by equivalent needle-gap. The third test gives natural frequencies, easily regulated to values of a million per second or more. The equivalent needle-gap will usually differ from the values obtained in test No. 2.

In both tests, No. 2 and No. 3, the potential is applied during several cycles of the oscillations. It has been found that some arresters do not discharge easily during the first half-cycle of the oscillation. Through considerations of the dielectric spark-lag and frequency, this characteristic affects the protective value of the arrester. Test No. 5 (half-wave test) brings out this characteristic. By inductive reasoning it can be shown that an arrester which has a half-wave equivalent spark-gap much greater than the disruptive-stroke equivalent spark-gap is not a good protector for low-frequency strokes. If the arrester does not spark over its gaps during the first half-wave, the insulation in parallel will be punctured unless the time of the first half-cycle of oscillation is less than the dielectric spark-lag of the insulation. In other words, such an arrester may give good protection at exceedingly high frequencies but decreases in protective value as the frequency of the lightning surge happens to be lower.

Summarizing, we have for the study of frequency effects on the arrester that:

Test No. 1 (direct-current static) is usually unavailable and unnecessary.

Test No. 2. Alternator gives two equivalent needle-gaps.

a. The needle-gap corresponding to the voltage by transformation (no arrester connected to the terminals).

b. The equivalent needle-gap as actually measured in parallel with the arrester.

Test No. 3. (Disruptive stroke) gives two equivalent spark-gaps, one for each test.

c. The equivalent needle-gap of suddenly applied potential (alternator as source), arrester energized previous to stroke.

d. The equivalent needle-gap of suddenly applied potential (static machine as source), arrester not energized previous to stroke.

The form of the equivalent needle-gap characteristic curves will usually give information concerning the effect of frequency by inductive reasoning.

Test No. 5. (half-wave test) gives one equivalent spark-gap.

e. Equivalent needle-gap which shows the sensitiveness during the early part of any surge.

B. Effect of rate and acceleration of discharge on the equivalent needle-gap. The rate of discharge is the value of the current carrying off the quantity of electricity which causes the strain on the insulation. Mathematically it is expressed as

$$I = \frac{dQ}{dt} = C\frac{dv}{dt}$$

It is the rate of decrease in the quantity of electricity, or it is the rate of decrease of potential. It is evident that the higher the rate of discharge, the less will be the liability of damage to the insulation. The rate of discharge (that is the current) varies inversely as the resistance in the circuit. The effect of the rate of discharge, as affected by resistance, is shown by the equivalent needle-gap characteristic-curve of the resistance of the arrester, especially using the disruptive-stroke test.

Before an arrester can have a rate of discharge (current) there must be an increase of current from zero (or normal) to the value considered. The rate of this increase is the acceleration of the discharge. Even if the final rate of discharge is high, it will be of little avail if it requires a relatively long time to reach the condition of rapid relief. The acceleration of discharge is the rate of increase of current. Mathematically it is expressed as $\frac{dI}{dt} = \frac{V}{L}$ when V is the potential of the lightning and L the inductance of the arrester in the path of the lightning. Since the potential of a lightning stroke on a line cannot be controlled or limited in any way except by overhead grounded wires or materials, the factor of inductance of the arrester must be reduced to its minimum possible value. Since the inductance of an arrester is normally very low, it will cause no appreciable voltage effect except at very high frequency, therefore the high-frequency disruptive test (No. 3) should be used to measure the inductance. In order to eliminate the other involved factors viz., dielectric spark-lag and rate of discharge, a wire of good conductivity may be carried over the contour of the arrester circuit and the equivalent spark-gap of this inductance taken. This equivalent spark-gap is inversely proportional to the acceleration. In general, arresters have negligible inductance as compared with the inductance of the earth connection.

C. *Effect of the quantity of lightning discharge on the equivalent spark-gap.* It should be noted that in this the quantity of dynamic electricity is not included. The quantity of dynamic electricity which follows the lightning stroke produces an effect on the endurance and arc-extinguishing power and should be considered under a different head. If the dynamic discharge causes the lightning surge, the quantity of electricity involved in the excess potential comes under this head.

The effect of quantity of electricity was incidently involved and discussed under rate and acceleration of discharge.

There are three means of increasing the quantity of lightning electricity:

1. By keeping the capacity constant and increasing the potential.

2. By keeping the potential constant and increasing the capacity.

3. By maintaining a current at high potential and allowing it to flow for a time. $Q = I\,t$.

If the increased quantity of electricity is obtained by an increase of potential, the duration of abnormal potential will be extended, since the logarithmic decrement remains the same. If the increased quantity of electricity is due to increased capacity, the natural frequency of the oscillations will be lowered inversely, proportionally to the square root of the capacity.

Increased quantity by increase of time requires the application of continuous power.

The quantity of lightning electricity which may be generated in a laboratory is usually small as compared with the induced stroke on a transmission circuit, but not always. The usual criticisms of laboratory tests are based on this fact. This condition is unfortunate, but does not prevent reasonable deductions from laboratory tests. For example, if increasing quantities of electricity up to the laboratory limit are used, and the equivalent needle-gap of arrester (*X*) continues to rise with the increasing values, it seems safe to conclude that any greater quantity on the line will give a still higher equivalent needle-gap. If the equivalent needle-gap of an arrester (*Y*) remains constant for all available values of quantity in the laboratory, the conditions on the line discharge will be more favorable to *Y* than to *X*, to say the least.

The equivalent spark-gap characteristic-curve taken with either the disruptive stroke test (No. 3) or the half-wave test (No. 5) will show effects of the increase in quantity of electricity. In test No. 3, the quantity may be increased by an increase in potential obtained by drawing out the *G* gap, or it may be increased by using larger condensers. In the second case the potential may be left constant, but the natural frequency of the discharge is somewhat lowered, according to the formula

$$n = \frac{1}{2\pi\sqrt{LC}}.$$

The quantity of electricity in the half-wave test depends on the electromagnetic circuit, dimensions, and on the value of current in the primary. Greater quantity, then, may be obtained by choosing a larger transformer or by increasing the value of the direct current.

The only known way of reducing the quantity of cloud-lightning charge on a line is by means of an overhead grounded wire or other overhanging material.

D. What is the nature of the dynamic current-suppressing device? To make this definite some of the known devices are herewith enumerated.

1. Arc suppressed by rectifying quality of zinc; example, multigap arrester.

2. Arc suppressed by elongation of the arc to extinction; example, horn gap, magnetic blow-out, and movable plunger or electrode.

3. Arc suppressed by increase of resistance; example, conglomerate materials, analogous to coherers.

4. Arc suppressed by counter electromotive force; example, liquid electrode.

5. Arc suppressed by fuses in series.

6. No arc to suppress; dynamic limited by condenser effect. Example, aluminum cell without series-gaps.

There are at least three features about the dynamic current-suppressing device which should be determined experimentally.

a. Does the device for the dynamic current also restrict the flow of the lightning current in any way?

b. How long does the device require to extinguish the dynamic current?

c. Does the extinguishment of the dynamic current set up secondary lightning surges on the system?

To answer question (*a*) the equivalent spark-gap should be taken under the widest range of conditions possible in the laboratory.

To answer question (*b*) a study of the oscillograms of the discharge is necessary.

To answer question (*c*) some knowledge may be gained by arcing in connection with inductances and capacities of variable proportions. Even line tests are feasible, using protected needle-gaps at different points to measure the rise of potential. Oscillograms will sometimes give an indication of surges, or possible surges under more favorable conditions, in the form of a sudden decrease of current.

E. *Endurance of the arrester.* Two conditions of endurance corresponding with the service conditions should be recognized.

1. Endurance to transitory lightning strokes at stated intervals.

2. Endurance to recurrent surges.

From observations of a number of thunder storms the general conclusion has been reached that two strokes of cloud-lightning follow each other either in rapid succession, one setting off the other, or only after an interval which may be reckoned in several seconds or minutes. The time between strokes will vary with the storms, but an interval of three to ten minutes was usual in one locality.

Starting discharges over an arrester in a laboratory test at intervals as great as three minutes, would make an endurance run of inconveniently great length. An arrester recovers from a stroke of lightning quickly, and it is necessary to give sufficient time only between strokes to dissipate the energy loss in the arrester. In most cases an interval of 10 sec. is sufficient to dissipate the heat, but in a number of cases the writer has used ¼ sec. with a total endurance of 10,000 strokes.

If the arrester is intended only for intermittent lightning strokes, the only rule that can be adopted is to make the interval sufficient to avoid damaging the arrester by carrying the effect of one stroke over to the succeeding one; such an arrester should be capable of successful operation also when the strokes come in pairs, the interval between the two strokes of each pair being in the range of one to ten cycles of the generator frequency. In the test record the interval should be noted.

If the arrester is designed for recurrent surges, its endurance is expressed in the number of minutes it will carry the continual train of discharges until the arrester no longer protects or is inoperative. Going out of operation may be the result of total destruction, destruction of some essential part, or increase of equivalent needle-gap to a dangerously high value.

F. *The dielectric spark-lag.* Although there are no commercial methods of measuring the dielectric spark-lag sufficiently developed to present at this writing, the subject is too important in lightning protection to leave without mention. Progress in the development of protective apparatus requires a recognition of its existence, and a further study of the cases where the dielectric spark-lag of an arrester involves a danger to the insulation. Any arrester involving the use of a gap in series has a dielectric spark-lag. Thus eliminating other defects, dielectric spark-lag is dangerous wherever it is possible to injure normal insulation placed in parallel with the arrester by subjecting both simultaneously to any kind of a lightning discharge. The converse of this statement, that the failure is due to the dielectric spark-lag only, is evidently not true. Each case must be discussed on its own merits based on the previously mentioned tests. The use of one or more series gaps necessarily involves a value of dielectric spark-lag. In reporting on the lightning-arrester it is necessary, for the present at least, simply to state whether the arrester has or has not series gaps; the use of series gaps does not condemn the arrester, although it is a distinguishing feature.

As a brief summary, recommendation of tests of lightning arresters should include at least the following:

1. The equivalent spark-gap characteristic-curve by the disruptive-discharge test.
2. The equivalent spark-gap at generator frequency.
3. The maximum discharge current at normal voltage and at double normal voltage.
4. The half-wave equivalent spark-gap.
5. The endurance of the device.

The principal protective apparatus to be considered are as follows:

1. Lightning-arresters.

The choice of arresters will usually lie among the four following types:

a. Multigap arrester.
b. Aluminum arrester (no-gap type and gap-type).
c. Liquid-electrode arrester.
d. Magnetic-blow-out arrester.

2. Lightning-arrester choke-coils or reactances.
3. Overhead grounded wires one or more, with or without lightning-rods.
4. Overload switches, either single-phase or multiphase.
5. Insulator protectors, horns or gaps, with or without fuses.
6. Static dischargers.
7. Earth connections.
8. Horn arresters with resistance.

The classifications of the circuits to be protected are as follows:

1. Constant-potential alternating-current overhead systems $\begin{cases}\text{grounded neutral}\\\text{non-grounded neutral.}\end{cases}$
2. Constant-potential alternating-current cable system $\begin{cases}\text{grounded neutral}\\\text{non-grounded neutral.}\end{cases}$

3. Constant potential direct-current systems.
4. Constant-current systems.

Comments on the protective apparatus. *a*. The multigap arrester has been used for years, and has been described and discussed elsewhere down to the latest designs. Its excellent qualities for discharging transitory lightning are well known.

b. The aluminum arresters are particularly well adapted to discharging continual lightning. They do not replace the multigap arrester, but complete the protection of a system by taking care of lightning which endangers the multigap arresters. Nearly all cases of destruction of the multigap arresters of the old design have been due to continual lightning. Every constant-potential system should have at least one installation of aluminum-cell arresters. This arrester is preferably installed on the bus-bars so as to take care of all feeders, and the multigap arrester on the feeders outside the switches for protection of the particular feeders. The aluminum arrester is a winter and summer arrester, as continual lightning is not directly due to cloud-lightning. The two types of aluminum arresters are the no-gap and gap types. The gap type is the cheaper and has a less maintenance expense, but the no-gap type is more effective.

c. The liquid-electrode arrester is recommended for potentials above 35 kilovolts, where the design of a multigap arrester is difficult.

d. The magnetic blow-out arrester has been used for several years. It is adapted to constant-potential direct-current systems.

2. Lightning-arrester choke-coils or reactances have the function of retarding high-frequency lightning traveling toward the station. This retardation gives the lightning-arresters time to relieve the lightning potential before it strikes the apparatus. This high-frequency lightning seems to come invariably from cloud-lightning, therefore the installation of choke-coils on the cable systems is unnecessary and not to be recommended. In many cases the installation of good lightning-arresters both inside and outside choke-coils is to be recommended.

3. Overhead ground wires. If a wire be placed underground it is protected from the static charge of cloud lightning. If the insulated wire is simply placed in a metallic sheath and hung overhead it is still protected from electrostatic charges from the clouds. Both these methods are often impossible of employ-

ment on account of the unjustifiable expense involved. The next best thing to do is to put the ground over the line wire. The farther above the line wire the grounded wire is placed, the better is the partial protection. Dr. Steinmetz recommends that an overhead grounded wire be so placed that two imaginary lines drawn from this wire 45° down from the horizontal will include all line wires between them. Each additional overhead ground wire, properly placed, gives some additional protection against induced static electricity from the clouds. The investment is the controlling factor in the choice.

The overhead grounded wire also has the function of protecting wooden poles from shattering by direct stroke of cloud-lightning. It also has the possibility of carrying a direct stroke of cloud-lightning to ground past the line wires without shattering the insulators or causing a short-circuit. More data regarding this point are needed.

Lightning-rods at each pole add a slight probability that a direct stroke will strike at the pole and not between poles.

If the overhead grounded wire is earthed at every pole, direct strokes of lightning are likely to find a more direct path to earth. The wave-front of a direct stroke is usually so steep that the charge finds the natural inductance of the horizontal wire a great impedance, and consequently it is likely to side-flash to other lines and also over insulators to its natural terminus, the earth. If the earth connection is made at every third pole there are of course more chances that a direct stroke will hit a midway point and have a greater distance to travel parallel to the line wire before it reaches the earth. The parallel movement of the charge gives electromagnetic induction on the power wires. Practically all reports of damages to lines by direct strokes confine the line damage to about seven successive poles. This fact is suggestive.

4. Overload switches are a part of the protective apparatus, especially on grounded neutral systems. Multiphase switches are usually installed and are to be recommended on all systems, like a cable circuit, where a short-circuit between phases follows quickly after a short-circuit from phase to neutral. On overhead grounded neutral systems, phase-to-phase short-circuits are less likely to occur, and consequently if three single-pole switches are used, the phase short-circuited may be opened automatically, and the load, if not excessive, may be carried on the remaining two wires with a ground return for a time.

5. Insulator protectors. An insulator protector is a single gap or horn gap placed beside the insulators and set with a gap-length such that a spark will just prefer to jump the gap to arcing around the insulator. The insulator should be in its wet condition. The use of this protector is based on the principle that if the arc must take place at the insulator, due to any high potential, it will guide the flames so that the insulator will not be cracked by the heat. The arc is then interrupted either by a fuse or by automatic trip-switches in the station. If no damage is done to the generator or transformers, the line can be immediately put back into service. Otherwise the line is out of service until the linemen locate and repair the damaged insulator. On most alternating-current railway circuits a momentary interruption of service is not very objectionable.

There are some evident objections to the use of the insulator protector.

In general, every electrical system should have some lightning protection. There is a certain minimum of protection below which it is not advisable to go. The amount of protective apparatus above this minimum will depend primarily on the value of the transmission apparatus and the value of continuity of service. Since there is a uniformity in these values in the various installations throughout the country, there is consequently a general uniformity of practice. There are, however, many special cases which require the careful consideration of every device described above. Such examples are found in large factories and industries depending entirely on continuity of electrical power, also in large lighting plants in cities. Thoroughly efficient protection is not much more expensive than partial protection, and is cheaper than carrying duplicate plants and apparatus, in addition to the repair bill and almost inevitable interruption of service when apparatus is destroyed. Arresters are of the nature of insurance. A reasonable percentage of the cost of the apparatus, cables, lines, etc., with the factor of the cost of repair of each kept in view, should be added to the monetary value of continuity of service. The sum thus found should be the limit up to which it is justifiable to make expenditures for protection and inspection.

Recommendations for protection of electrical plants in general. These recommendations will vary with the class of circuit to be protected.

1. Constant potential alternating-current overhead systems.

The first consideration is the question of connecting up grounded neutral or non-grounded neutral (this includes straight delta connection). The answer is somewhat influenced by the kilowatt capacity of the generating apparatus and the multiplicity of the circuits. In general it may be stated that the distinguishing troubles on a non-grounded neutral system are primarily potential or internal-lightning troubles; these may finally result in a short-circuit which becomes a current trouble. On the other hand, in the grounded neutral system the initial trouble is usually a short-circuit which may become an internal-lightning surge when the abnormal current is suppressed. Until the advent of the aluminum arrester there was no way of taking care of the continual lightning on a non-grounded neutral system, due to a phase becoming accidentally grounded, and consequently practice has been favoring the grounded neutral connection. It seems safe to predict that the non-grounded neutral connection will now become more favored on account of the possibility of operating for an indefinitely long time with a grounded phase.

Insulators often fail one at a time, and such failure causes a short-circuit in the grounded neutral connection. The subject of overload-switches has already been discussed above.

On a non-grounded neutral system the aluminum arrester is absolutely essential. On a non-grounded neutral system it is advisable to use an aluminum arrester to take care of the preliminary continual oscillations which sometimes precede a short-circuit, and afterwards to take care of the low-frequency energy surge that sometimes results from the interruption of the short-circuit current. In the case of multiple circuits an aluminum arrester in a station may be used, connected directly to the bus-bars. Multigap or other arresters for transitory lightning should be installed on each line or feeder, and lightning choke-coils should be used in each phase between the arrester and bus-bars. Line arresters should be used on the line at high altitudes, exposed lengths, fractional multiples of the line length to catch standing waves, and in the usual path of thunder storms. Transitory lightning-arresters should be installed on all incoming and outgoing lines in conjunction with choke-coils in every sub-station. An aluminum arrester is probably unnecessary, in general, in each sub-station, but in some cases it will be advisable to install another arrester at the extreme end of the line.

When low-potential systems are fed from high-potential systems special precaution should be taken to prevent the destruction of the arrester, and then of the low-voltage apparatus over the entire system by the accidental impression of the high voltage on the low-voltage system. This may happen either through electrostatic induction or direct connection of the two systems. Continual and continuous lightning are produced on the low-voltage system. The multigap arrester without series resistance will short-circuit by welding the cylinders and thus save the apparatus. An aluminum cell will take care of this condition without interrupting the service, but the arrester must be of special design, as it may have to operate continuously at its critical voltage until the fault is removed. If it is only electrostatic induction through the step-down transformers the design is easy, but if it is a direct connection between one phase of the high-potential system and the low-potential system, the aluminum cell must be capable of carrying the condenser current of the high-potential line until the fault is removed.

One substantial overhead wire well-grounded is a justifiable investment on nearly all overhead systems. Two driven iron pipes as earth connections are recommended, or one pipe and the usual wire to the bottom of the wooden post. Using large copper plates buried in the earth is as a rule unnecessary.

Earths. Make an earth connection as near the arrester as possible, even if it must be a relatively poor earth, then extend the earth connection to two good earths. It is advisable to measure the ground resistance each year before the thunder storms appear and to be assured that it is low.

Constant-potential cable systems. The choice of grounded or non-grounded neutral is again up for choice, as the conditions in a cable system are quite different from those of an overhead system. From a protecting standpoint the difference lies in the fact that the phases are as a rule throughly isolated from one another in the overhead system, and an arc fed by the capacity current of the line can play from one phase to ground without affecting the insulation between phases, but in the cable the capacity currents are much greater, and an arc from phase to ground quickly melts and burns away the insulation between phases. In the usual multiple-feeder system there is not time in this short interval to locate and disconnect the faulty feeder. Since a short-circuit is to result anyway and open the circuit-breaker, practice has favored the use of the grounded neutral connection. This avoids most of the continual surges due to a grounded phase on a non-grounded neutral. The aluminum arrester will protect against the continual surges, and if there are only a few feeders, some evident advantage may be gained by using the non-grounded neutral connection.

The circuit should be broken as quickly as possible after an arc starts, or the heat from the flame will cause widespread damage to adjacent cables and wires. This is especially true on large, high-current systems where even normal current could quickly burn up considerable cable. The engineer should take note of the effect of the heat of an accidental arc and use non-inflammable separations for the cable. Asbestos covering or brick barriers are to be recommended in manholes or at terminal bells.

Unless there is some special reason for not doing so, the cable sheath should be thoroughly and frequently earthed. It is undesirable to make the sheath carry currents of fusing values, or to allow even a small arc to play upon the sheath to the earth in any spot, especially where inaccessible.

Except the transitory lightning due to switching, all surges on a cable system are continual. Therefore the multigap, or any other arrester involving an arc in the discharge, is not so well suited for this system as the no-gap aluminum arrester. No choke-coils need be used on a cable system.

Mixed cable and overhead system. The only addition to what has been said of each system is the statement of the advisability of installing arresters at the junction point of the two systems.

4. Constant-potential direct-current systems have been satisfactorily protected by the single-gap arrester, notably the magnetic blow-out type. In the future it is probable that the no-gap aluminum arrester will find an application where cloud lightning is especially severe and where the conditions warrant the extra expense.

5. On constant-current systems the peculiar conditions permit the use of a simple horn gap with a suitable series resistance.

Although this paper has been carried to an unusual length, not all the salient features of each subject treated have been discussed. It is hoped, however, that enough has been said to assist in bringing the practice in protective apparatus out from the somewhat indefinite speculative stage and to establish the foundation of methods and tests which will place the engineering on the same reasonable basis as that of other electrical branches.

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25, 1907

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PRACTICAL TESTING OF COMMERCIAL LIGHTNING-ARRESTERS

BY PERCY H. THOMAS

Introductory.[*] The question as to what tests for commercial lightning-arresters might be properly incorporated in the standardization rules of the American Institute of Electrical Engineers has lately been considered by the Standardization Committee. The committee finally decided not to adopt any lightning tests in the new edition of the rules adopted June 21, 1907. However, the sub-committee on lightning-arresters hopes to get a full consideration of the subject for the benefit of a later Standardization Committee. The present paper, together with another paper on the same subject by Mr. E. E. F. Creighton, is prepared at the request of the sub-committee to serve as a basis for discussion. As no lightning-arrester tests have ever been included in the standardization rules the initial treatment should now receive especially careful attention.

Some idea of what constitutes suitable subject-matter for the standardization rules of the Institute must be assumed at the outset. It is the opinion of the writer that the purpose of the standardization rules should be to give such directions and information for the comparison and test of commercial lightning-arresters as may be likely to be of general practical use, and which are of such a character as to be generally agreed to and accepted by engineers having experience with the use or design of lightning-arresters. This subject-matter need not be limited to specific tests or specifications, but may properly include general considerations, suggestions of forms of making tests, of apparatus, etc. Individual personal opinions, as to the superiority of particular designs of arresters, specific tests about the value of which there is not a general agreement, untried tests, and, in general, purely theoretical considerations should be omitted.

Research work covering the effects of various conditions on the performance of lightning-arresters, the investigation of really new types, for example, electrolytic arresters; and the best conditions for determining the detail of designs, etc., is of great importance and should be actively encouraged. But such matter properly finds no place in the standardization rules.

All information and tests embodied in the standardization rules must be sufficiently general to be applicable under all conditions within their terms; for example, a test applicable only to high-voltage alternating-current arresters should not be recommended in such broad terms as to be applied to direct-current railway arresters.

This matter must be capable of being readily understood by any electrical engineer having experience with plants, likely to require the lightning-arresters under consideration. No such person should be expected to have to make a special investigation of new types of apparatus or new method of test to carry out the rules. All rules should be such as not to favor any particular manufacturer's apparatus.

Tests may be made to determine:

1. The condition of individual arresters.
2. The effectiveness of a particular design.
3. The characteristics of different types.

In general there will be little occasion for testing the condition of individual arresters, since inspection will usually reveal any defects in the materials or construction. The relative advantages of the different broad types of arresters will in most cases be determined by general considerations and consensus of opinion, rather than by definite tests. It is therefore with individual designs that practical tests on commercial arresters will be found most useful, and here such tests will be of very great benefit. For example, from time to time new commercial arresters appear, advocated by comparatively irresponsible persons. These arresters very often have little protective value. Such arresters, especially on lower voltages, although they are by no means confined to such voltages, find a ready sale entirely independent of their merits, and the more frequently, since engineers of low-voltage plants are often not at all familiar with the lightning-arrester problem. If a standard test generally accepted and capable of easy application can be determined, the detection of such practically worthless arresters will be a comparatively easy matter. Similarly, the necessity of commercial trials on a large scale of special forms of high-tension arresters which have a very limited protective power, may be eliminated by suitable comparative tests. Again, if generally accepted tests were at hand for the criticism of commercial arresters, the designs of many of these arresters would undoubtedly be overhauled and perfected so as to appear to advantage under such tests. If the tests were wisely chosen a distinct advance in the art would follow.

In testing the effectiveness of individual designs, one of the most important features to be determined is the insulation strength of the apparatus to resist the static strains existing during actual discharge.

Tests should undoubtedly be made to cover auxiliary apparatus as well as arresters proper, for example, line choke-coils.

Conditions of actual operation. A recital of the various ways in which lightning and other static disturbances can affect an exposed commercial circuit has been often made. Practically all result in the equivalent of the production of a sudden rush of electricity, or wave, or surge along a line wire. Such a surge usually passes both ways in the wire until it is discharged, dissipated, or reflected. There is obviously no upper limit to the electromotive force which may be applied to a line wire by lightning, and the wave or surge may be theoretically of any frequency. As a matter of fact, however, since extremely high frequency—for example, 100,000,000 million cycles—must necessarily be associated with extremely small electrostatic capacities, in the writer's opinion such very high frequency disturbances need not be here considered. (See appendix I.)

The distinctive characteristics of the static surge or wave are its abnormal frequency and the fact that it is not directly supported by the power of the generator. It should, of course, be remembered that these surges not only produce strains to ground and between line wires, but they frequently cause concentration of potential between turns of windings in coils, especially near the terminals.

Resonance, being usually supported directly by the power of the generator, will not be cared for by lightning-arresters and is here omitted from consideration.

There is another possible source of potential rise of a static character; namely, the sudden interruption of a current flowing through inductance, such as the inductance of a transmission line. It is evident that a short-circuit including the whole or a portion of the transmission system, will store a relatively large amount of energy in the inductance thereof; if by any means such a short-circuit current be abruptly interrupted, a very high potential will result, being limited only by the electrostatic capacity of the lines and their insulation strength. It is the opinion of the writer, however, that this condition never occurs where large currents are involved, since the condition predicated for producing the short-circuit provides also a discharge path for any voltage rise, and since the very energy stored in the choke-coil will tend to maintain the current uninterrupted until the major portion of this energy is dissipated. When, however, in the case of the opening of such a short-circuit as in an open-air arc, the extension of the length of the arc proper has reduced the current to a value where it becomes relatively unstable, there will be a tendency for the arc to go out suddenly, causing the *remnant* of the energy originally remaining stored in the inductance, to produce a rising potential. This residue will, however, never be more than a small portion of the maximum energy stored. A great many direct tests of the opening of circuits through enclosed fuses and circuit-breakers, where conditions have been definitely known to be as assumed, have shown practicably negligible rises of potential. The fact that high voltages have appeared in electric accidents coincidentally with short-circuits and arcs is no proof that these high voltages have resulted from the sudden interruption of heavy short-circuit currents.

The severity and general range of the static disturbances actually materializing within an electric system is definitely limited in certain ways.

A. The maximum voltage of a surge passing along a line must be limited to the voltage which will cause a discharge to earth over the line poles. That this is an effective limitation is shown by the great number of transmission poles which have been shattered by lightning. It is natural to suppose that on this account, transmission lines having steel poles will not make as heavy demands on the terminal protective apparatus as lines having wooden poles, since the discharge to earth can presumably occur much more readily on the former. It remains to be seen, however, whether the added annoyance of grounds and cracked insulators where the steel poles are used, does not more than offset the advantage of the discharge from the wire over insulator to ground.

B. Disturbances of very small energy, and hence very high frequency discharges, can be neglected, since the electrostatic capacity of the terminal line wiring and apparatus will be such as to absorb their energy without serious rise of potential.

In general, then, it is the opinion of the writer that we are safe in concluding that we have to deal only with static waves or surges of potential not over a few times line potential on extra high-tension circuits; namely, high enough to discharge to ground over the insulators, such surges having frequencies usually very high with regard to normal frequency, but not what is generally understood by extremely high frequency; for example, practically never reaching fifty million cycles a second.

Lightning-arresters should discharge without serious rise of potential and without otherwise disturbing the system, this specific type of "static,"—not static disturbances in general, nor all kinds or forms of that can be devised or produced under laboratory conditions,—but merely static discharges actually occurring under the limitations imposed by commercial plants.

Choke-coils, static interrupters, or reinforced insulation must serve to protect windings from local concentration of potential under the same limitations as to the character of the static disturbances as above.

It should be stated in this connection that to enable an arrester to exert its protective function properly, it is necessary that all the insulation of the system, including the apparatus and the lines shall be high, and especially that it be high against *static disturbances*. Bushings and surfaces are often broken down much more easily by static than by normal frequency strains. It is by the strengthening of the insulation of the system that immunity from lightning has been in the past most readily obtained and will in the future be most effectively increased.

TESTS

Discussion and specification. The discussion in the paper will be confined to lightning-arresters for electric lighting and power circuits, alternating and direct current. Such arresters may be of many types having radically different characteristics and structures. For the sake of clearness it will be well to enumerate the principal of these types:

Multigap arresters, with series or shunt resistances or both. These arresters are used practically only on alternating-current, constant potential. The multigap feature is, of course, introduced on account of its non-arcing power.

Arresters relying for the suppression of the generator arc upon the blowing of a fuse or upon the opening of a circuit-breaker.

So-called horn arresters.

Magnetic blow-out arresters.

Electrolytic arresters.

Many special types, including such arresters as the waterjet, the Gola, the Wurts railway arrester, and many others relying on special materials or special forms for their non-arcing power or discharge characteristics.

The features of arrester apparatus most susceptible of satisfactory tests are perhaps:

A. The initial break-down voltage.
B. The static equivalent during discharge.
C. The circuit-opening power.
D. The insulation strength.
E. The ability to stand repeated discharges.
F. The choking power and insulation strength of choke-coils and equivalent apparatus.

HOLDING NORMAL VOLTAGE

General considerations. The determination of the voltage necessary to cause an arrester to discharge is of importance; first as ascertaining the minimum voltage at which protection begins; secondly, the margin of safety which the arrester has in order to secure itself against continuous break-down. The second consideration is of special importance in the high-tension arresters, especially voltages of 30,000 and above.

On very high-tension circuits the power of multigap lightning-arresters to hold the normal line voltage is very greatly affected by attendant conditions; for example, the electrostatic capacity of the intermediate unconnected cylinders forming the gaps causes a break-down to occur at a much lower voltage on high frequency than on low frequency. This subject has been fully discussed before the Institute, for example, in connection with the following papers:

"Methods of Testing Protective Apparatus" by E. E. F. Creighton; see discussion by Chas. P. Steinmetz, TRANSACTIONS, Vol.

XXV, 1906; "Protection against Lightning, and the Multigap Arrester," by D. B. Rushmore and D. Dubois. TRANSACTIONS, Vol. XXVI, 1907, and "Multigap Lightning Arresters with Ground Shields," R. B. Ingram, *Electric Journal*, April, 1907.

Since the capacity of these gap cylinders is increased by the nearness of grounded objects, the placing of arresters near a wire or transformer case or similar object, or more particularly in the neighborhood of other arresters or line wires on another leg of the circuit, tend very greatly to increase this effect. The effect is so marked that an arrester entirely capable of holding the line voltage with a good margin of safety, if installed apart from other objects, will be utterly unable to hold normal voltage if installed in close proximity to another arrester connected to a different leg of the line. From this it follows that tests to determine the power of an arrester to hold normal voltage, must be made under conditions equivalent to those under which that individual arrester is to serve. The writer suggests that on voltages of 40,000 volts or higher, an excess of air-gaps may be provided, and the exact number required to give a proper margin over line voltage be determined by trial after final installation.

Too sensitive an adjustment of the series-gaps of an arrester on very high tension circuits will be the cause of the greatest annoyance, and probably will result in the destruction of the arrester. The resulting frequent discharges of the arrester will oftentimes be laid to abnormal static, due to some unknown cause, when as a matter of fact the only difficulty is the ease with which the arrester discharges on slight impulses of high frequency or even fluctuations of abnormal voltage. This condition has in the past, often been a source of great annoyance in commercial plants where it has frequently not been recognized; it should always be carefully borne in mind.

Description of test. The actual measurement of the breakdown voltage of an arrester can best be made at normal frequency. In making this measurement, the primary object is to determine the margin of safety in the arrester over the normal line voltage as read on a voltmeter. Thus in this particular instance the use of the needle-point spark-gap for measuring the voltage as provided in the standardization rules, though always of value, is not as directly the criterion sought, as the voltage determined by the voltmeter. In making such a measurement, all the conditions provided in the standardization rules under "Insulation Tests" should be followed, where applicable. The writer suggests that where practicable, the determination of the breaking down voltage of arresters on 40,000 volts or over be made from the main generator of the system with the arresters and neighboring apparatus in final position.

It is true that high-tension multigap arresters will break down at a much lower voltage on high-frequency electromotive force than on normal frequency; but, in the opinion of the writer, since this phenomenon is in the direction of safety, and since it has been established by actual experience on high-tension plants that this fact does not cause discharges on arresters frequently enough to be troublesome, this may be accepted as a favorable characteristic of such arresters. This matter is, however, properly a subject for investigation and research.

MAXIMUM IMPEDANCE OFFERED TO A DISCHARGE—NEEDLE-GAP EQUIVALENT

General considerations. The maximum impedance offered to a discharge determines the protective power of an arrester, and is therefore of the greatest importance. On the other hand, since so little can be definitely determined as to the type of discharges actually to be met, and so much depends upon the characteristics of the circuit and apparatus being protected, it is impracticable at the present time to devise *absolute* tests of a general character which are not likely to be uncertain or misleading. It is of course easy to choose condensers and circuits, and apply static to arresters under a great variety of conditions with presumably considerable variation in results, but in the opinion of the writer such tests, except where they can be shown to be reasonably within the conditions existing in a transmission line, should not be specified for the testing of commercial arresters, but should be considered as proper subjects for investigation and research. However, comparative tests between arresters may be often made to great advantage.

If an arrester be subjected to a high-frequency discharge from a condenser, and its static equivalent measured by the equivalent needle-gap method, the numerical result will depend upon the character and method of operation of the testing apparatus; for example, it will depend on the electrostatic capacity of the condenser, the inductance through which it discharges, the voltage to which it is charged, the auxiliary circuits providing for the charging of the condenser, and the disposition of the arrester itself. Since it is manifestly impossible to determine upon any reasonable number of definitive conditions as representing the transmission line under all conditions, no general absolute test should be attempted as such; that is, no attempt should be made to treat each arrester as having so many units of protecting power irrespective of conditions of service and of test.

The study of arresters through the agency of condenser discharges has been an absolute necessity in the progress of recent years. This progress has been notable. Tests with any reasonable form of condenser discharges, as distinguished from applications of normal frequency, will show practically the same characteristic results, although numerically different frequencies and different circuit arrangements, etc., will show variations. Consequently, to get what advantage is practicable out of such tests, the natural course would seem to be to use some condition, or conditions, of condenser capacity, etc., known to be reasonably well within the conditions of actual operation and reasonably easy of realization, and then to make comparative tests for what they may be worth. By this means a large part of the value of a complete range of static tests will be obtained. Any further data that might be found by multiplying the tests under different conditions, would probably produce only small changes in the actual conclusions; such additional tests are more properly subjects for investigation and research than for practical tests of commercial arresters.

Taking up these tests more in detail, the various types of arresters will be separately considered, since their needle-gap equivalents are controlled by radically different features.

1. *Arresters offering no impedance to the discharge.* Such arresters rely on special features for suppressing the generator arc. Examples are the fuse type, the horn type, and the magnetic blow-out type. If a horn arrester has also a series resistance, it is no longer properly a horn arrester but a series resistance arrester. It is obvious that the maximum impedance offered to a discharge by this type is practically equal to the initial discharge voltage, and no further test is required than has been already indicated under the head of holding normal voltage. This type of arrester is especially effective in discharging the line.

In connection with these arresters, the question must be raised, however, that it is theoretically possible for the device relied on for interrupting the generator current to introduce a rise of potential. This question can be determined finally only by experience. The definite data available at the present time, derived from direct tests, have, as far as the writer is aware, failed to indicate any serious rise of potential from the operation of fuses, horn, or magnetic blow-out arresters. The question is, however, somewhat a matter of controversy.

2. *Arresters with series resistance.* Series resistance must necessarily offer some impedance to a static discharge. The amount of this impedance will depend upon the value of the resistance, on its inductance and its capacity, on the abruptness of the application of the charge, and upon the inductance through which such charge must pass. Any inductance in the series resistance will tend to impede the discharge; any capacity, however, either internal or with other objects, will tend to facilitate the discharge. The higher the frequency; that is, the greater the abruptness of the discharge, the greater will be the relative importance of the inductance and capacity in the series resistance in comparison with the ohmic resistance.

It is evident that the danger to apparatus introduced by the series resistance will be negligible if the discharge be small enough, or may theoretically be dangerous with the lowest resistance if the discharge be abrupt and heavy enough. Since both the magnitude and abruptness of the discharges which can be produced in a commercial system are limited by certain maximum conditions, it becomes an open question just how much danger will result in practical operation from a definite series resistance.

Series resistances for lightning-arresters have been designed on two principles; first sufficiently to cut down the generator current following a discharge to render the device easily non-arcing and to prevent all burning of cylinders; secondly, usually with multi-gap arresters, to allow as free a discharge as possible while still maintaining the non-arcing quality. In the latter case the shunt resistance has ordinarily been used as well, and helps decidedly in cutting down the minimum allowable series resistance. Experience shows that the first mentioned high series resistance does seriously impede the static discharge on commercial lines and it has been practically abandoned as a means of principal protection, though somewhat used to carry off the so-called slowly accumulated charge. The low series resistance is much used on all types of alternating-current circuits except those of lower voltages; it can hardly be considered at present as finally determined, whether or not the present "minimum value" series resistances offer serious opposition to actual discharges on commercial systems. In most cases they do not.

The determination by test of the impedance offered by a series resistance arrester to a static discharge is hardly practicable, since such resistance will ordinarily constitute practically the major portion of the resistance in the test circuit, so that whatever the discharge voltage may be, it will of necessity be impressed upon the series resistance. The needle-gap equivalent would then be merely a measurement of the voltage and quantity of current in this particular test, and not any inherent characteristic of the arrester. Some idea of the relative value of two arresters may be obtained by connecting them in series, passing a discharge through, and measuring the needle-gap equivalent of each arrester. As far as the writer knows, this particular form of test has rarely been made. Obviously, a comparison of the ohmic value of the series resistances of two arresters generally similar, will give a good idea of their relative effectiveness. Where the types of series resistance are, however, entirely different, a comparative test by putting the two in series and subjecting them to the same discharge, or some equivalent test would be necessary for forming a trustworthy judgment.

3. *Special forms of arresters.* Under this head are included as above, arresters relying on special forms and special materials for their non-arcing power, and arresters having an unknown construction. Here will be classified many new types of arresters, especially low-voltage forms which appear from time to time, but are not founded on well-recognized principles and are presumably of doubtful utility.

These types are generally found to be intermediate in their characteristics between groups 1 and 2 above. They are not like group 1, in which the maximum impedance to a discharge is practically independent of the character or strength of the discharge, nor are they quite like group 2 in which the needle-gap equivalent is more or less directly proportional to the severity and abruptness of the discharge; their equivalent is usually found to increase slowly with increasing severity of discharge. It is in these special groups that direct tests by discharge of condenser through the arrester are of the most service. Such tests may be made to give a measure of the impedance offered to the discharge, as compared with that offered by some standard well-known arrester, thus giving data for the judgment of their effectiveness where inspection and the results of commercial service are insufficient to determine the merits of the arresters.

In view of the compactness of construction of most lightning-arresters, there is always an opportunity for a discharge to break down insulation or jump an air-space, short-circuiting a portion of its normal path. Such action is of course likely to destroy the arrester and shut down the system, since the non-arcing features will ordinarily be thereby crippled. The test with a severe condenser discharge may be made to serve the function of testing the insulation of the arrester. This is one of the tests most needed and most easily made, and should be strongly recommended. In actual practice a great many arresters have failed on both high-tension and low-tension circuits from discharges jumping between parts or to ground, and allowing the generator current to follow. When these tests are made without the power lines being connected to the arrester, care must be taken to detect the occurrence of internal sparks, as they may not otherwise be noticed.

Description of test. The test to determine the impedance offered to a discharge may be best made by discharging a condenser directly through the apparatus to be tested, and measuring the maximum voltage across this apparatus by a needle-point spark-gap. The measuring spark-gap may either be so set as to take the discharge half the time, while the apparatus takes it the other half, or it may be so set as just to fail to take any discharges. The former condition is presumably the better one, since to make a spark-gap take all the discharges when connected in parallel with an arrester it is sometimes necessary to increase the gap a very considerable percentage. This percentage will depend upon all sorts of conditions not definable or controllable, so that a very considerable source of variation will be introduced into the measurements, if the method of entirely suppressing the spark in the measuring gap be adopted. The needle-point gap taking half of the discharges will be the comparative equivalence of the impedance voltage offered to the discharge.

Spark-gap. The condenser should always discharge over a spark-gap to reach the apparatus to be tested. This is the element which introduces the high frequency. This spark-gap should preferably be large enough to cause a voltage to be impressed upon the arrester very much higher than the normal voltage of the circuit upon which it is to be used—where possible perhaps three times normal voltage. The tests will of course be of value even if a considerable lower discharge potential be used.

Condenser. The electrostatic capacity of the condenser should preferably be considerable, because it is intended to reproduce to some extent the more severe conditions of practical experience. A pair of high- or low-tension line wires will ordinarily have a capacity in the neighborhood of one hundredth of a microfarad per mile. It is thus seen that where several lines are connected to the same bus-bars near the arrester, a considerable capacity may discharge over the arrester. It is difficult to tell just what portion of a line wire near the discharge point should be considered to discharge directly through the arrester, since the inductance of the line becomes very considerable and tends to delay the discharge of the more remote parts, allowing the arresters more time to pass off the excess. (See Appendix II). It is suggested as a compromise value that where practicable a few hundredths of a microfarad be utilized. This figure is admittedly open to discussion. Capacity can be most easily measured by determining the charging current taken on a *true sine* electromotive force at a known frequency and voltage; one microfarad takes three-eighths of an ampere approximately at 60 cycles and 1,000 volts.

It may further be added, that it seems practically very unlikely that any considerable length of transmission line can be raised at one time to an excessively high potential by any static disturbance. The total length of line simultaneously affected, could hardly exceed a few miles at most. Where so much capacity as here recommended is not available, since all such tests must be relative, a considerably smaller condenser will give valuable results. High voltage rather than extremely large electrostatic capacity is recommended.

Abruptness. The condition of extreme abruptness in a test, which is one of the severe conditions, is obtained by having no impedance, other than the arrester directly, in the discharge path of the condenser and by limiting the length of the connecting wires in such path to a few feet. The initial abruptness of the discharge (though not the frequency of oscillation) depends solely upon the inductance and resistance in the discharge path; it is not lessened but rather increased by enlarging the capacity of the condenser. It is of much more importance in making the discharge sudden, that the inductance in the discharge path of the condenser be eliminated, than that the electrostatic capacity of the condenser be large. The character of a discharge is indicated by the sound. The " crack " should be extremely sharp and loud.

Circuits. In providing means for charging the condenser conveniently (except where using a static machine), it will usually be necessary to prevent the current supported by the charging apparatus from being maintained through the lightning-arrester after a discharge. This might oftentimes burn out a resistance.

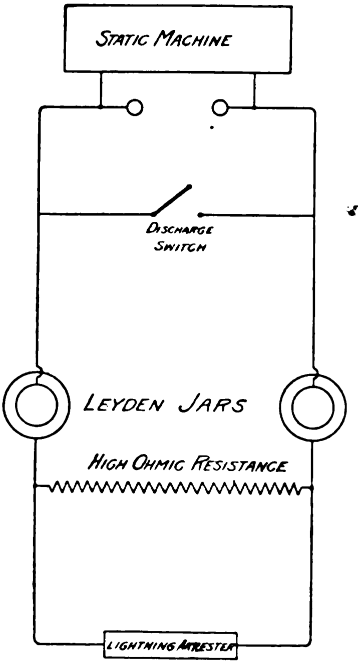

FIG. 1—Diagram of circuits for testing impedance offered by lightning-arrester to a discharge—static machine and leyden jars

A variety of connections may be utilized for these tests, two of which are shown in Figs. 1 and 2. Others may be devised.

Where laboratory apparatus and laboratory skill are available and the voltage is not too high, the arrangement in Fig. 1, utilizing a frictional or static generator, will be found convenient and compact. Under other conditions, however, static machines are often not available; they are very troublesome except in the hands of persons especially expert, and in general will be found less satisfactory than the connections in Fig. 2. The arrangement shown in Fig. 1 is substantially that described by Mr. Creighton in a paper before the annual convention of this Institute in 1906, Vol. XXV, of the TRANSACTIONS.

It is, of course, possible to utilize the circuits of Fig. 1, substituting for the static machine a step-up transformer connected to an alternating-current main. A switch will then be used across the high-tension leads of the transformer to start the discharge. There must usually be some current-limiting device in connection with the transformer, to prevent too much current flow on the closing of the switch. This arrangement should give a satisfactory source of static discharge.

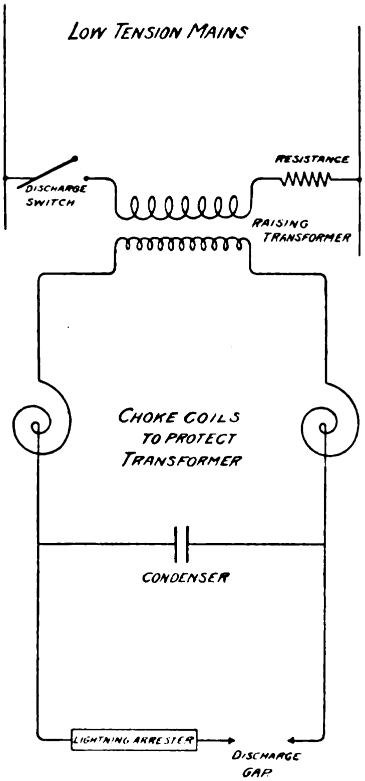

FIG. 2—Diagram of circuits for testing the impedance offered by a lightning-arrester to a discharge—alternating-current mains and step-up transformer

In Fig. 2, alternating-current is used to charge the condenser through a step-up transformer and the discharge is produced by the closing of a switch, as shown. This switch must ordinarily be opened rapidly, to prevent the generator current from following a discharge over the series-gap through the arrester. The resistance or inductance in series with the primary of the transformer also serves to limit the generator current. Such a switch may easily be made by mounting a contact on the end of a pole some feet in length, arranged to swing past a coöperating contact point; this will close and open the circuit rapidly enough to get a single discharge over the series-gap with each closing.

By using a very high ratio in the step-up transformer and suitable values of the inductance or resistance in the primary, it is often possible by leaving the switch closed, to produce a rapid succession of practically pure static discharges over the series-gap through the arrester. Apparently under these conditions the condenser charges and discharges each alternation, and all generator current is suppressed by the inductance or resistance. This continuous spark method should be used with great care, and only when the actual suppression of the generator current in the arrester has been demonstrated. This condition is favorable for making a very large number of discharges in a short time, but is very hard on the arrester; as, for example, in case of a puncture of insulation. It can be more readily obtained when, instead of a generator of considerable power and choke-coils or resistance in the low-tension side of the transformer, a small generator be used having its field weakened very much below normal value, and a transformer ratio chosen much greater than necessary to break down the discharge gap. In this case the field reaction kills the generator voltage as soon as the condenser discharges over the series-gap. This is a very effective arrangement but is not always available, as it requires a special generator.

Construction of condensers. Condensers may be conveniently made up in a number of ways.

Leyden jars in sufficient quantity are satisfactory, though the writer has not found them nearly as convenient as other forms. The capacity of a leyden jar having 50 square inches of foil coating inside, and having a glass wall approximately three thirty-seconds of an inch thick is somewhere near 0.0005 microfarads.

Glass plates with tin-foil cemented on them, and placed in a rack, are effective but easily broken.

Sheets of metal between sheets of solid insulating material such as oiled cambric or oiled paper, either in or out of oil are quite satisfactory.* This type of condenser, though inferior in point of dielectric loss, is extremely compact, is easily constructed of materials readily obtained, and is quite robust. The leads are preferably brought out from each condenser plate separately, so that the capacity and insulation strength may be varied by connecting the plates in different combinations.

Tests of choke-coils. Although lightning-arrester choke-coils and other forms of auxiliary apparatus accomplishing the same purpose, do not serve the same function as lightning-arresters, yet the impedance offered to the discharges from the line is of importance, since it is the function of the choke-coil to offer as large an impedance as practicable to such surges as may pass an arrester. Comparative tests of the impedance values of choke-coils are especially desirable at the present time, since there is very little data on the relative choking power of the more usual designs of such coils, and their relative merits are not easily determined otherwise. These tests do not involve very much difficulty in the making, and when made as comparative tests serve an important function.

The same apparatus and method of tests as described for testing the impedance of arresters to discharge, may be utilized in connection with two or more such coils in a series, one being a standard for purposes of comparison. The needle-gap should be taken on each of the two coils under the same or similar conditions, and a comparison of results will show the relative power of these coils. By this same means the insulation strength of the coil and the spacing of its leads can be tested.

POWER TO SUPPRESS THE GENERATOR ARC

General considerations. This all-essential feature of an arrester is unfortunately extremely hard to test and determine in the general case, since the difficulty of suppressing a generator arc increases with larger and larger currents and will be multiplied many times when the generator circuit includes much inductance. With many arresters, tests made on anything less than a full-size plant cannot give a safe guide for judging the non-arcing power of an arrester, since only on such plants can the maximum generator current be obtained. Designs behaving perfectly satisfactorily in many laboratory tests on medium-size machines, or on large machines with limiting resistances, may very likely fail utterly to suppress the arc when placed upon regular commercial circuits. In a paper presented concurrently herewith and supplementary to a paper by the writer read at the annual convention of the American Institute of Electrical Engineers in 1902 on the " Function of Shunt and Series Resistance in Lightning-Arresters," are shown some curves of the non-arcing power of multigap arresters on alternating-current circuits, which are the result of actual tests and show this fact in a very marked manner.

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*The capacity of a plate condenser may be calculated fairly closely from the formula: Capacity in microfarads = the area of one plate in square inches divided by the thickness of dielectric in inches $\times 2.25 \times$ the specific inductive capacity $\times 10^{-7}$. The specific inductive capacity of air is 1 and of solid dielectrics from 3.5 to 6.

This condition is not of an imaginative nature, since this very difficulty has occurred a great many times. It is very seldom that conditions are favorable for making such tests, as they require, except with an arrester inherently limiting the generator current, practically the exclusive use of a large generating plant; and because short-circuits may be produced frequently, there is great danger of damage to the generating apparatus. It is of course true that lightning-arresters, themselves limiting the flow of current from the generator, need be tested on circuits only just large enough to supply without material drop of potential, the current naturally taken by the arrester. In all cases it should be definitely determined that no more current would be supplied during the discharge were the generating capacity infinitely large, otherwise the test would not be trustworthy. Also it is important that, where necessary special inductance should be introduced into the circuit to represent any inductance which might be found in an actual power system; as, for example, the inductance of a transmission line. The presence of such inductance markedly increases the difficulty of suppressing the generator arc.

Speaking broadly, it may often be determined from general considerations whether an arrester will be non-arcing or not, in which case tests will be unnecessary. In practically all free-discharge, non-arcing arresters, the tests of non-arcing quality will cause destruction of the arrester and usually of several arresters. Considering more particularly the bearing of the various arrester types on tests of non-arcing power, the following should be noted:

a. A number of arresters utilize a free discharge path to earth, with means brought into action after the passage of the discharge for suppressing the arc. Such are the fuse-type arrester, the horn arrester, the magnetic blow-out arrester, etc. The horn type is sometimes used in connection with series resistance or with a fuse, in which case it should not be classed as a horn arrester but as a resistance or fuse arrester.

The ability of these arresters to suppress the generator current then becomes a question of the ability of the fuse, the horn form or the magnetic field to open the circuit. There seems to be no doubt of the ability of a properly constructed fuse, usually of an enclosed or explosive type, to open any circuit. Numerous tests have been made on this subject. There is a good deal of question as to the ability of horn arresters to open promptly very heavy currents. Magnetic blow-out arresters are used only on low voltages where they have a very decided arc-opening power.

b. Arresters of the series resistance type. When the series resistance is very large, the maximum generator current will be low, and there will be no question as to the non-arcing character of the arrester.

When the series resistance is made as small as possible, as is usually the case in connection with the multigap shunt resistance arresters which are much used for high alternating-current pressures, the design of the arrester is usually somewhere near the lower limit of non-arcing power and tests will be of value. The factors determining the non-arcing power of multigap arresters, with or without shunt resistance, have been pretty thoroughly investigated. As a matter of fact, with a given inductance in the circuit, the number of gaps required to suppress the generator arc with a high-tension alternating-current circuit increases at a rate between the first and second power of the current. With increase in inductance in the circuit it also rapidly increases at a given current.

c. The types of special material or special form arresters already referred to, including arresters of unknown method of operation, will be found generally to have characteristics intermediate between those of the two classes above mentioned, and very little can be inferred as to their non-arcing power aside from tests, unless the results of actual experience have been sufficient. Unfortunately, with special forms on high voltages, for reasons already explained, it is often very difficult to make adequate tests. For low voltages, alternating and direct-current, however, it is relatively easy to make tests, and they are often to be recommended, especially where claims are made for some unknown arrester which has not been widely and publicly used.

Description of test. The tests of non-arcing power are made by reproducing operating conditions; that is, connecting an arrester across a powerful supply circuit and passing a static discharge across the whole or a part of the arrester to initiate the generator arc. The generator capacity should in all cases be sufficient to supply without material drop in voltage, all the current which the characteristics of the arrester will allow it to take. On this account tests on horn and fuse-type arresters and other types not limiting the flow of generator current on discharge are rarely practicable. When made on smaller machines, or by limiting the current flow by resistance or otherwise, they are of little value.

The *inductance* corresponding to the maximum inductance to be expected in service, should be included in the generator circuit.

Source of static discharge. It is a very troublesome matter to obtain a satisfactory source of the static discharge. Where a Holtz or frictional machine is available, and the voltage is not too high for this machine to cause a discharge, it may be satisfactorily used. In most cases, however, it will be found more satisfactory to get the high-tension discharge from a transformer. An arrangement similar to that already described for testing the impedance offered to discharges by arresters, may be here utilized. In this case a much smaller condenser may be used than for the above test, and the voltage need be only just high enough to cause the discharge. It is essential in such a test to avoid synchronism, that the source of discharge be not taken from the same supply as the generator, since if the static waves have always the same relation to the waves of the generator, all conditions of practice would not be obtained. If special pains should be taken to adjust phase relations to give the discharge at the most severe point of the wave, the same source might be used, but this method is difficult and uncertain.

Evidently, in order to get the most unfavorable condition for suppressing the generator arc, the discharge should be passed over the arresters in the early part of the cycle of the generator wave, since this allows maximum of heating or other activity in the arrester before the first zero point.

The actual severity of the exciting static discharge seems to be unimportant in this work; a comparatively slight spark is entirely sufficient.

Protection of apparatus. It is necessary in practically all cases to protect the generator by powerful choke-coils or static interrupters, from the strains produced by the static discharge utilized to jump the arrester. It is desirable as well, unless otherwise provided for, to protect the high-tension side of the charging transformer by means of choke-coils or other apparatus from a short-circuit due to the condenser discharge across its leads.

Timing the discharge. The production of the exciting spark at the proper time of the cycle may be accomplished by a small synchronous motor driven from the supply and arranged to close the circuit at the proper time, as described in papers by E. E. F. Creighton on " New Principles in the Design of Lightning-Arresters," read at the March meeting, 1907, and " Methods of Testing Protective Apparatus," read at the annual convention, 1906, or it may be accomplished by the swing-switch method already described, in which case a number of trials must be made with each setting of the apparatus to ensure the reaching of the worst condition, since the point within the cycle at which the discharge occurs is largely a matter of accident. From 20 to 50 trials should be made under each condition. This method is preferable to the synchronous-switch method, as so much dependence need not necessarily be placed on the accuracy of the operating mechanism. Oscillograph curves are here, of course, a great safeguard.

Auxiliary Apparatus. It is very desirable in tests of this sort to have an adjustable resistance controlling the flow of current from the generator, which can be cut out gradually until the maximum condition is reached. Such a resistance must be of a very robust and well-insulated character. It is also necessary to have in circuit an entirely reliable circuit-opener of some sort, such as an oil-switch or a fine-wire enclosed fuse. Either arrangement may be made satisfactory.

It is, of course, of interest and value to have oscillograph records of the currents and voltages of the tests, but as this involves a great deal of work in setting up the apparatus and is not wholly necessary, the oscillograms will often be omitted.

It should be noted in testing alternating-current multigap arresters utilizing shunt resistance, that if when the static discharge is produced at the early part of the cycle, no current follows into shunted gaps, the discharge should be produced at a somewhat later point of the alternation, as this will be more favorable for the initial starting of current in the shunted gaps.

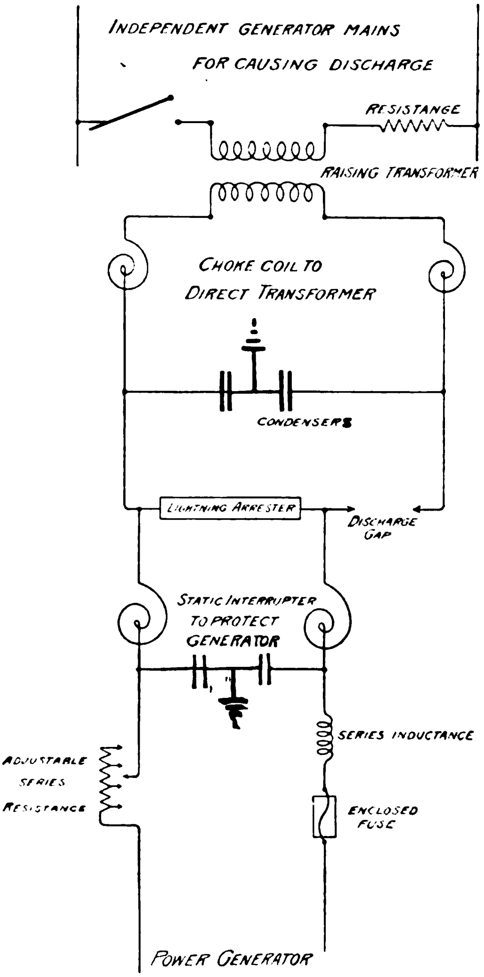

FIG. 3—Diagram of circuits for testing non-arcing power of lightning-arrester

Thus, in the case of shunted gaps the most critical point of the cycle for the discharge is different from what it is in the case of plain series gaps.

One diagram of connections for testing the non-arcing power of arresters is shown in Fig. 3. This is capable of various modifications. Reference is suggested to the various papers above referred to by Mr. Creighton and the writer. The arrangement shown by Mr. Creighton is presumably satisfactory where applicable.

Attention is again called to the fact that except where arresters have an inherent faculty of limiting the flow of current, tests to be of value must be made upon high-capacity generators and circuits; they are then very troublesome to make and involve considerable danger to the generator and other apparatus connected to the test circuit both from the heavy short-circuits and from static strains. Line choke-coils playing practically no part in the arc-suppressing power are not involved in this test.

Disturbance of operation. When the discharge of an arrester offers a free path for the flow of generator current, the result is the lowering of the line voltage to such an extent as to cause synchronous apparatus to drop out of step, and, in view of the heavy current taken by the arrester, the opening of the circuit-breakers or the blowing of fuses. This is a most serious matter in practical operation and has caused a great many shut-downs. These shut-downs are serious, as the whole system must be started again, including the synchronizing of generators, synchronous motors, and synchronous converters. The critical conditions evidently are the generator current taken during the discharge, and the length of time before its suppression; for example, a current strength which in one alternation would be insufficient to open a circuit-breaker might, if continued for a dozen alternations, cause this result. Arresters which sufficiently limit the generator current following the discharge will cause no disturbance; and arresters suppressing the generator current within an alternation or so will undoubtedly cause no trouble, however great this current. Arresters utilizing series resistance and drawing only a few times full-load current would not be expected to open breakers or throw out synchronous converters; fuse arresters utilizing a small wire-enclosed fuse which open the circuit very quickly are probably safe, but horn arresters and their equivalent will usually disturb the system.

Tests to determine whether or not a definite arrester will in general cause this trouble are impracticable, for the different settings of breakers, the different designs and loads of synchronous apparatus, together with the different location of discharges, will render a general determination out of the question. However, it may often be concluded from general considerations that an arrester cannot even take current enough to disturb the system, or that it is sure to take current enough to cause trouble.

Under specific sets of conditions, as at some particular plant, by selecting the most sensitive condition, it may be determined by trial whether an arrester discharge is likely to cause disturbance of the operation, by repeating the test just described for determining the non-arcing power of arresters. This will, however, usually be considerable of an undertaking and not worth while.

Capacity for frequent discharges. It goes without saying that every arrester should be able to withstand as many successive discharges as it may meet in actual service. Unfortunately this condition is exceedingly variable and impossible of general determination. High-voltage arresters will presumably discharge much less frequently than will low-voltage arresters, as in the former minor disturbances will not be able to pass to the ground. Furthermore, on alternating-current circuits at least, discharges occurring at one part of a cycle are more severe than discharges occurring at another, which tends to relieve the arrester. Under the conditions in which tests for non-arcing power are feasible, tests to determine the capacity for frequent discharges may be made. The parts particularly subject to deterioration under these conditions are series and shunt resistance, magnet-coils, and the cylinders in multigap arresters.

On low-voltage circuits, direct and alternating, where working conditions are more easily reproduced, such tests are often feasible. On high-tension alternating-current circuits, however, they are not often worth while.

Tests for determining capacity for frequent discharges should be made as already described, for determining the non-arcing power of arresters. A number of discharges should be produced n succession at intervals of some seconds, the exact number of repetitions and the intervals being determined according to the circumstances of the case.

Deterioration, etc. There are a number of other characteristics of great importance in the choice of arresters which, however, cannot readily be made a subject of test. Arresters should be robust; the resistances should be of a character not to corrode or otherwise deteriorate with time; they should be as simple as possible and the parts likely to deteriorate should be replaceable.

To require a renewal by hand after a discharge, before an arrester is ready for a second discharge, is a serious handicap.

Conclusion. It is evident from the analysis of the advantages, disadvantages, and limitations of the various possible tests of lightning-protective apparatus, that certain tests are of great value in connection with certain types of arresters, but not with all types, and that some of the tests are difficult and awkward to make. It would thus seem that tests should be introduced into the standardization rules cautiously and gradually.

On the other hand, there will be a great advantage in many cases in testing lightning-arrester apparatus; for example, a ready means of correctly sizing up the numerous low-voltage arresters, especially railway arresters, which appear from time to time is desirable. Furthermore, the fact that certain tests have the stamp of approval of the Institute will do much to cause designers to put their apparatus in condition to meet the tests, even if the tests be so inconvenient as rarely or never to be imposed. Again, a careful consideration of a properly chosen set of rules will help materially to give to electrical engineers who have not paid much attention to static phenomena a clear idea of the fundamental conditions to be kept in mind.

The following tests are suggested for general consideration as suitable for the approval of the Institute:

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1. In all lightning-arrester design the insulation strength should be required to stand the abrupt application of the discharge of a condenser of at least 0.01 microfarad capacity charged, to a potential three times normal arrester potential, and not less than 50,000 volts, without sparking between parts or to ground. Where it is inconvenient to get a discharge of this severity, arresters, alternating-current and direct-current, for not over 3,000 volt lines can be roughly tested with a smaller capacity or lower potential, but no tests with capacity less than 0.0025 microfarads or voltage less than 30,000 should be relied upon.

2. Break-down voltages at normal frequency should be determined in all cases, following where applicable, all the requirements laid down in the standardization rules for the testing of insulation strength.

On voltages of 40,000 and higher, the test should if possible be made with the arrester installed in position, and in any case with the same relation to surrounding grounded or charged objects as it is to have in final installation.

3. Where general considerations are not sufficient to determine the amount of impedance offered to a discharge, comparative tests between arresters may be made by noting the needle-gap equivalents of two or more arresters, by passing across the arresters separately or in series the discharge of a condenser of a few hundredths microfarad capacity charged to a potential not less than 50,000 volts, nor less than three times the normal voltage of the arrester. This test will be of relatively little value with an arrester including series resistance of equivalent characteristic, since the test will show simply the voltage of the discharge in each case. Such comparative tests may be made with smaller capacities and lower voltages, though they will not be as trustworthy.

The impedance offered the discharge should be measured by a needle-point spark-gap in shunt to the terminals of the arrester, and set to take half the discharges. The needle-point gap should be shielded by metal if near the main discharge-gap.

4. Where general considerations are not sufficient to determine the non-arcing power of an arrester, a test may be made by passing sparks over the arrester when connected to a source of electromotive force of sufficient power to supply without dropping its potential, all the current which the arrester will take. In no case need a generator power be used, greater than the maximum to which the arrester is to be subjected. In all cases the maximum series inductance to be found in service must be included in the generator circuit.

With arresters which offer no impedance to the discharge, such as the horn type, the fuse arrester, and the multigap arrester without series resistance, etc., reliable tests can be made only on the maximum generator power to which the arresters are to be exposed.

Non-arcing tests are difficult and dangerous for apparatus in all cases except where the generator current is strictly limited. The testing apparatus should be protected both from the static discharge and from the effects of the short-circuits.

5. Endurance tests may be made in the same manner as tests of non-arcing power. The discharges should be repeated at intervals of some seconds. The exact interval and continuance of test must be a matter of judgment in each individual case.

This test is especially useful and feasible in connection with low-voltage arresters, such as direct-current railway types.

6. In addition to the behavior of arresters under the above tests other features should receive consideration; for example, the disturbance of normal operation caused by a discharge, robustness and permanency, simplicity, whether or not replacement is required after a discharge, etc.

As the only final test of a lightning arrester is actual experience extending over considerable time and repeated in many places under different conditions, no general conclusions should be drawn from short-time trials. Such a determination usually requiring years, the considerations and tests enumerated above are of great practical value in determining the relative merits of different types of apparatus.

APPENDIX I

The reasons for concluding that very high frequencies do not have to be considered in the protection of commercial lines may well be somewhat elaborated. Since the quality which renders the discharge of a static surge of a given magnitude exceptionally difficult is very great abruptness, that is, very sudden arrival of charge, we should here consider not strictly the frequency of discharges, but rather the form of the initial wave-front. Strictly speaking, the term frequency is applicable only where there is an oscillating current or potential. The term abruptness of discharge is more generally applicable. This abruptness of charging depends upon the time required for a given point to pass from normal to a given abnormal potential. This time is especially short with very high charging potential and low inductance in the charging path.

Every lightning-arrester has some capacity; so have the line wire outlets, insulator tie-wires, and every conductor or patrol conductor connected with the line. Consequently, to raise the potential at the lightning-arrester discharge-gap to a dangerous point, a certain amount of charge is required. Since this charge is transmitted to the arrester by the line wires, there will be a minimum length of wire which will be sufficient to store charge enough to cause this rise of potential. Such a value as ten feet of line wire would seem to be very conservative as the minimum limit of capacity which could store sufficient energy to produce material strain. The capacity of two transmission wires 10 feet long is approximately 1.5×10^{-5} microfarads. It is hard to imagine a possible case in which such a length of wire can be abruptly charged through a path having less inductance than that of 5 feet of such a transmission wire, which will be about 4×10^{-6} henrys. Consequently, since the time of the complete discharge period of a condenser through an inductance is $= 2\pi\sqrt{C\,L}$, in which expression capacity may be farads and inductance henrys, the frequency of discharge of this condenser through this inductance will be approximately 20,000,000, per second. This is presumably the maximum frequency which need ever be considered in a transmission line, and even this is probably too high.

The only conclusion to be drawn from the above is that in a general way we may neglect the effects of any disturbances having a higher frequency than a few million periods per second. It is of course true, however, that since the inductance and capacity of the transmission line is distributed, the above formula cannot be applied directly thereto. The true results will not differ radically from those derived by the assumptions made. As further reducing the probability of harmful effects being produced by very high frequencies, it should be noted that every irregularity of form, every insulated tie-wire, every branch connection of any kind, or leakage into air over insulators, and any current set up in other conductors, tend, especially with very high frequency, further to break up an advancing wave and also to dissipate its energy.

A few outer turns of a transformer winding have a large enough electrostatic capacity to be of very material moment in keeping down potential rises from very high-frequency discharges; for example, consider the outside layer of a transformer coil, which may be taken as three-fourths of an inch wide. Such a transformer as would be connected to a high-tension transmission line would have perhaps a mean length of turn of six feet, giving an exposed area on the top and edges of the first layer of about 75 square inches. The mean distance of such a layer from grounded objects, or objects acting as though grounded for the necessary brief instant of time, would be not far from two inches in a high-tension transformer. The specific inductive capacity of the insulating material is at least three, giving a capacity of 2.5×10^{-5} microfarads. This is equal to about 10 or 15 feet of transmission line. This estimate is probably very much too low, since if the frequency is high enough so that only the first layer is affected, the next layer or two will act as though grounded and will increase the capacity of the first layer ten or twenty times. In other words, as far as the protection of transformers from ground is concerned, there must be a very considerable volume of charge at high potential passed into the winding before a jump to ground will result. The immediate leads of the transformer are presumably protected by this capacity, and indeed they add some capacity of their own. On the other hand, station wiring gets no benefit therefrom, when the transformers are disconnected.

In general, then, in view of the fact that there must be in all commercial lines at or near the arrester a certain minimum capacity, which in a general way for the purpose of discussion may be assumed as at least equal to 10 or 15 feet of transmission line, no disturbances involving a materially less capacity can cause serious damage. Consequently, no higher frequencies than can occur in connection with the minimum capacity need be considered in lightning-arrester work. This frequency will probably not exceed a few million per second. The same general line of reasoning applies to low-tension line wires. With these, the values of electrostatic capacity and all leakage factors are greater than for high-tension lines.

APPENDIX II

There are certain limitations in the severity and possible forms of discharges from commercial transmission lines which are important in considering the impedance offered to discharges by various designs of arresters.

The exact maximum electrostatic capacity that can ever in a commercial circuit be so located as to be abruptly discharged through a lightning-arrester is very difficult to estimate accurately. The conditions of the test recommended for measuring the impedance to discharge of an arrester are very severe, more severe probably than are likely to be met with in practice, for the following reason: In the test recommended, the total charge of the condenser is passed directly against the arrester through only the impedance of a few feet of wiring. In an actual transmission plant there can be connected so closely to the discharge path of the arrester only 100 or 200 feet of line and at most a few high-tension transformers. This capacity will be increased somewhat by tie-wires, insulator surfaces, bushings, outlets, etc. Taking these things together, however, the capacity within a few feet's discharge of the arrester will fall far short of a hundredth of a microfarad. On the other hand, there may be in the immediate neighborhood a capacity considerably larger than this amount. Such excess of capacity, however, must discharge through some tens or hundreds of feet of transmission line, which will very much reduce its severity on the arrester discharge.

Neglecting the concentrated capacity closely adjacent to the arrester which has already been described as limited to a quantity presumably much less than a hundredth of a microfarad, the current passing from the transmission line proper may be likened to the discharge of water from a long uniform trough. If such a trough filled with water be allowed to discharge by the opening of one end there will be a sudden rush as the water accumulated at this end passes out, but this rush will be immediately followed by a steady stream of water of practically uniform section while the trough empties itself. The rate of flow at the outlet once established on this steady basis will not change materially until after the " falling " wave which passes backward reaches the end of the trough and is reflected again toward the outlet. Similarly with the transmission line; assuming it to be charged to a very high potential and the discharge to start at one end over an arrester, there will be an initial rush of the charge stored in the immediate neighborhood of the arrester (this would include that stored in bushings, transformers, branch wires, etc.), but when once this charge, which is limited in amount by the conditions already stated, has once passed, further charge will flow out of the line through the arrester at a more or less uniform rate which is determined by the relative inductance and capacity of the transmission line, but which thus produces no steadily increasing demand on the discharge capacity of the arrester. If, instead of the whole transmission line being charged to this high potential, the disturbance be one of high frequency, this is equivalent simply to shortening the trough of water or the transmission line and will relieve the arrester so much the more easily.

Evidently an arrester which discharges somewhat slowly will have a harder task to perform, since the distance of the farthest charge which can discharge directly through the arrester on the initial breakdown without material opposition from line inductance will extend to a greater distance; for example, an arrester with series resistance will be more likely to receive an absolute direct discharge from as great a capacity as a hundredth of a microfarad, than will a fuse-type arrester.

Even in the severe condition in which a direct stroke of lightning reaches the transmission wire at 1000 feet from the arrester, a similar limitation exists, since all charge above that necessary to bring the potential of the line wire to the point of breaking to earth from the line over insulators, is discharged directly to ground, and, as before, we have only the charge on the transmission wire to be discharged over the arrester. There is, however, one exception; namely, when the lightning stroke is continuous for some relatively considerable period of time, in which there will be a transfer of current over the line wire through the arrester to ground, not in the form of a wave or surge (relying on the distributed inductance capacity for its transmission), but as an ordinary current in a conductor governed by the impedance of the line. In this case the effect of the inductance of the line and the arrester discharge path will soon disappear leaving the resistance of the line and of the arrester to withstand the voltage of the discharge. How common such a condition is at the present time is a mere matter of speculation.

Mr. R. P. Jackson in his paper of last December on "Recent Investigation of Lightning Protective Apparatus" called attention to the fact that there is a limit to the amount of discharge current which can be obtained from the electrostatic capacity of a transmission wire at a definite voltage regardless of the length of the line.

It may be thus concluded that there is a surprisingly low limit to the severity of the discharge which an arrester can be called upon to discharge from a transmission line, and it is the opinion of the writer that the "several hundredths of a microfarad" recommended by this paper in the test for measuring the impedance offered to discharges is justifiable principally to give a margin of safety and to provide in the most practical available manner for the fact that the actual arrester will have to discharge lines charged to a considerably higher potential than that of the test, which. of course, renders the condition more severe.

The writer wishes to take this opportunity to make the plea that it would be far better in discussing lightning-arrester problems to avoid expatiating upon what we do not know and cannot know about lightning, and statements to the effect that the conditions are infinitely various and incomprehensible; and to make a serious effort to determine and explain such limitations and facts as we may know and can determine from known laws and from experience. If this be done the subject will lose most of its mystery, operating engineers will be able coherently and intelligently to observe and judge by what they see, and the advancement of lightning-protection will be very much facilitated.

APPENDIX III

Various papers bearing upon the reaction of lightning on transmission lines, and of the various characteristics and performances of lightning-arresters for light and power circuits have appeared from time to time in the TRANSACTIONS AND PROCEEDINGS of the American Institute of Electrical Engineers. For convenience they are here enumerated.

"Lightning Arresters and the Photographic Study of Self-induction." E. G. Acheson. Vol. VI, 1889.

"Some Possible Modifications in the Methods of Protecting Buildings from Lightning." N. D. C. Hodges. Vol. VIII, 1891.

"Lightning Arresters and the Discovery of Non-arcing Metals." Alex. J. Wurts. Vol. IX, 1892.

"Discriminating Lightning Arresters and Recent Progress in Means for Protection against Lightning." Alex. J. Wurts. Vol. XI, 1894.

"Theoretical Investigation of Some Oscillations of Extremely High Potential in Alternating High Potential Transmissions." Chas. P. Steinmetz. Vol. XVIII, 1901.

"Static Strains in High-Tension Circuits and the Protection of Apparatus." Percy H. Thomas. Vol. XIX, 1902.

"The Function of Shunt and Series Resistance in Lightning Arresters." Percy H. Thomas. Vol. XIX, 1902.

" The Grounded Wire as a Protection against Lightning." Ralph D. Mershon. Vol. XXII, 1903.

" Safeguards and Regulations in Operation of Overhead Distributing Systems." W. C. L. Eglin. Vol. XXII, 1903.

" Protection of Cables from Arcs Due to the Failure of Adjacent Cables." W. G. Carlton. Vol. XXIII, 1904.

" The Protection of High Pressure Transmission Lines from Static Discharges." H. C. Wirt. Vol. XXIII, 1904.

" High Power Surges in Electric Distribution Systems of Great Magnitude." Chas. P. Steinmetz. Vol. XXIV, 1905.

" An Experimental Study of the Rise of Potential in Commercial Transmission Lines Due to Static Disturbances Caused by Switching, Grounding, etc." Percy H. Thomas. Vol. XXIV 1905.

" Some Experiences with Lightning Protective Apparatus." Julian C. Smith. Vol. XXIV, 1905.

" Notes on Lightning Arresters on Italian High-tension Transmission Lines." Philip Torchio. Vol. XXIV, 1905.

" Performance of Lightning Arresters on Transmission Lines." N. J. Neall. Vol. XXIV, 1905.

" Some Experiences with Lightning and Static Strains on a 33,000-Volt Transmission System." Farley Osgood. Vol. XXV 1906.

" Methods of Testing Protective Apparatus." E. E. F. Creighton. Vol. XXV, 1906.

" Protective Apparatus for Lightning and Static Strains." H. C. Wirt. Vol. XXV, 1906.

" Recent Investigation of Lightning Protective Apparatus." R. P. Jackson. Vol. XXV, 1906.

" Lightning Phenomena in Electric Circuits." Chas. P. Steinmetz. Vol. XXVI, 1907.

" Protection against Lightning, and the Multigap Lightning Arrester." D. B. Rushmore and D. Dubois. Vol. XXVI, 1907.

" New Principles in the Design of Lightning Arresters." E. E. F. Creighton. Vol. XXVI, 1907.

" Notes on Hydroelectric Plant Organization and Operation." Farley Osgood. Vol. XXVI, 1907.

" Potential Stresses as Affected by Overhead Conductors." R. P. Jackson. Vol. XXVI, 1907.

CURVES OF THE NON-ARCING POWER OF MULTIGAP LIGHTNING-ARRESTERS AND THE SHUNTING POWER OF OHMIC RESISTANCE.

These curves and descriptive data are supplementary to a paper by the writer read before the annual convention of the American Institute of Electrical Engineers in June, 1902, and entitled, " The Function of Shunt and Series Resistance in Lightning Arresters." In the original paper the principal conditions governing the non-arcing power of multigap arresters on constant potential alternating-current circuits were discussed. The results from which these conditions were determined had been plotted in the form of a series of curves which were not at that time published. These curves which are the result of a very large number of tests at several voltages and on various circuits are here reproduced.

These curves although not to be interpreted with minute accuracy, which would be out of the question in work of this character, are believed to be thoroughly reliable under general commercial conditions. They are, of course, not of absolutely general applicability, since for example, practically all the tests were made with gaps at or near one-thirty-second of an inch, and would presumably not hold closely for widely different lengths of gap; also the curve showing the shunting power of ohmic resistance is plotted on the assumption that the number of series and shunt-gaps is approximately the same. There are, however, so far as the writer is aware, no limitations such as have just been mentioned, which are not clearly stated either in connection with the curves themselves or in the original paper referred to.

It is expected that these curves will be of interest in connection with the papers to be presented concurrently herewith on the subject of the testing of lightning-arresters.

The general method of making these tests is fully described in the original paper, and consisted in passing static sparks repeatedly, at instants of time determined by chance, across a series of gaps which were connected to a generating system including resistance and inductance where necessary, so that a known current would flow through a known inductance upon short-circuit. The number of gaps was varied in repeated trials until it was determined how many would always suppress the arc following a static discharge, and also what was the greatest number of gaps which could be made to fail. Similarly with the shunting power of resistance. With known conditions of short-circuit current from the generator, static discharges were passed repeatedly until both the condition of failure and the condition of minimum successful operation were obtained.

The tests on 12,500- and 25,000-volt circuits were made on one or two generators of 5,000 h.p. capacity having an exceptionally large flywheel capacity. It will be noted in the curves that free short-circuit currents were not taken from the generators. The currents actually used were, however, increased up to the point where burning of the cylinders became a limiting factor for commercial work. It is obvious from the form of the curves that larger currents flowing from the generator would greatly reduce the non-arcing power of the gaps and ultimately eliminate it.

It may be stated that a line of lightning-arresters adapted to all voltages from 2,500 to 50,000 has been designed from these curves. In some five or six years of operation, so far as the writer knows, they have never shown any failure to suppress the generator arc. In a very few instances where by some accidental means a portion of the gaps has been cut out or a part of the resistance short-circuited trouble has occurred, but this cannot be considered a failure of the arrester to be non-arcing.

Fig. 1 shows a number of one-thirty-second of an inch gaps necessary to suppress the generator arc under the worst condition of static discharge with different initial short-circuit amperes, and with different amounts of inductance in the generator circuit, and applies on circuits of 2,500 volts, 3,000 alternations. Each curve is for a definite inductance.

On 2,500-volt circuits the non-arcing power is nearly inversely proportional to the initial current up to 500 or 600 amperes with a low inductance.

Fig. 2 shows similar curves for a 4,800-volt circuit both at 3,000 and 7,200 alternations with various inductances.

On 4,800-volt circuits the non-arcing power is still nearly inversely proportional to the initial current, especially with low values of inductance. The increase of the inductance makes an enormous decrease of non-arcing power.

Fig. 3 shows similar curves for 12,500-volt circuits, at 3,000 alternations. It should be noted in this figure that the very high values of inductance cause an enormous decrease in the arc-suppressing power of the cylinders. This shows how little can be determined as to the non-arcing power of a given arrester arrangement without a knowledge of the inductance in the circuit. It will also be noted in this figure that in general the curves bend up more sharply than before, showing that the

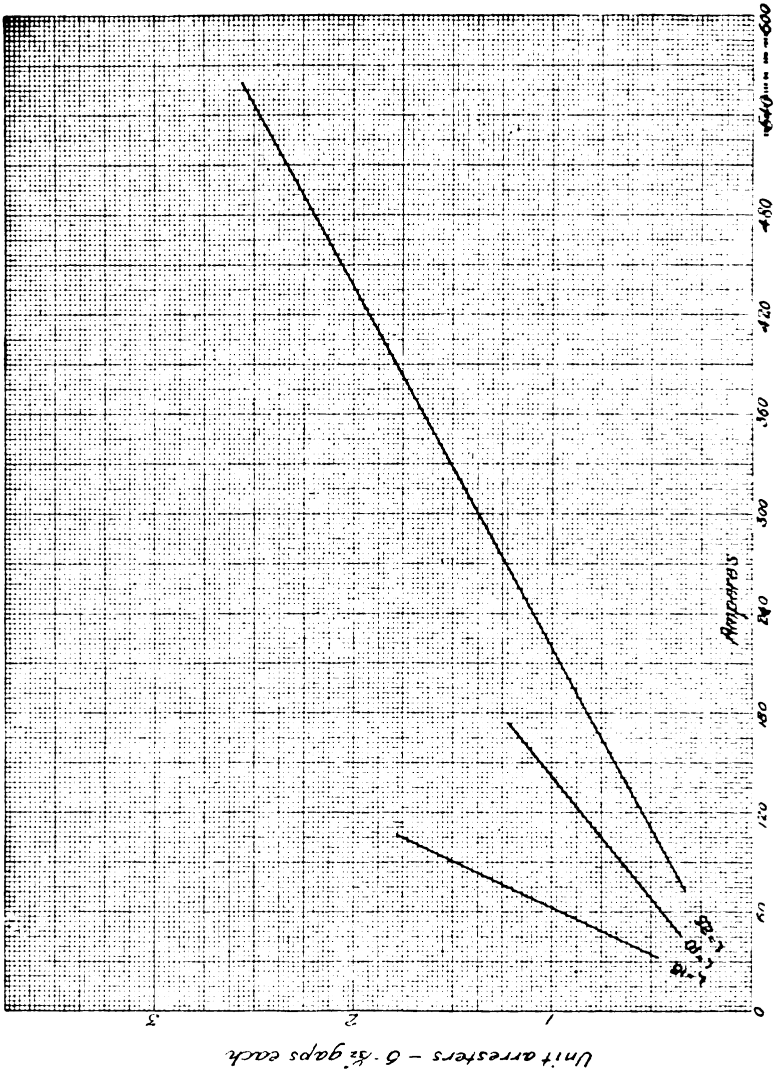

FIG. 1—Number of gaps necessary to suppress the generator arc with various initial short-circuit currents for different values of inductance in circuit, 2,500 volts, 3,000 alternations

high tension brings in a condition which is very exacting on the arc-suppressing power of the arresters.

On 12,500-volt circuits the effect of the usual amounts of inductance found in commercial circuits becomes more important, and the non-arcing power drops and begins to decrease more rapidly than the initial current increases.

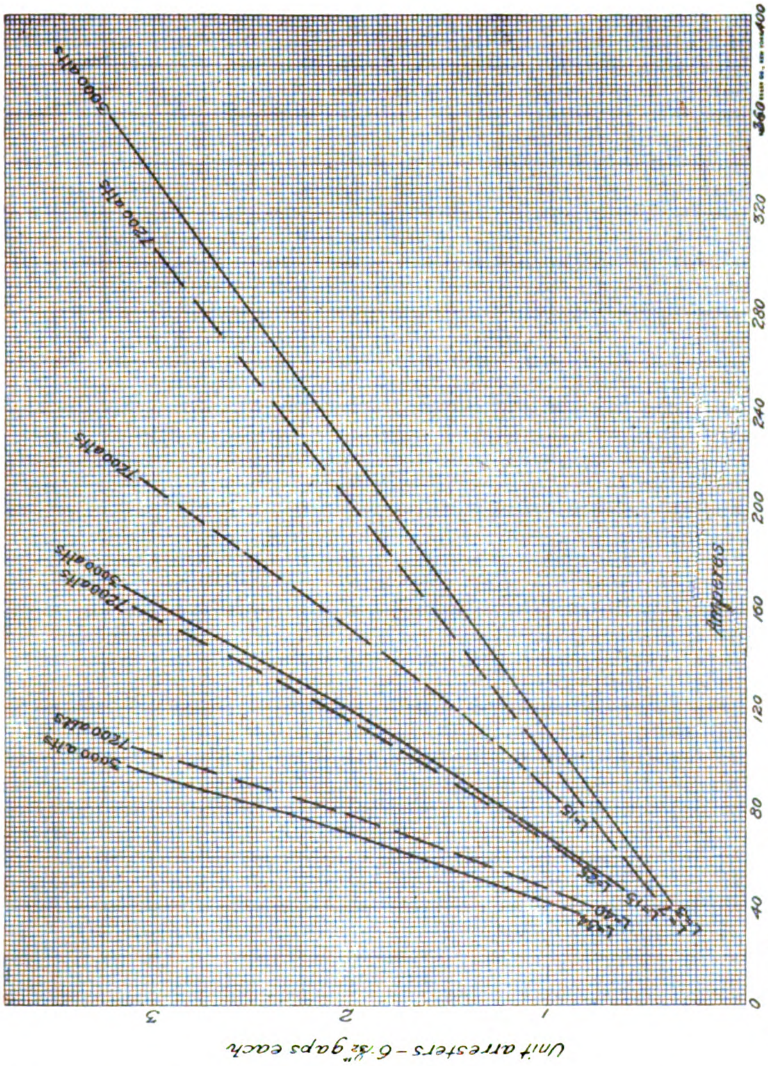

FIG. 2—Number of gaps necessary to suppress the generator arc with various initial short-circuit currents for different values of inductance in circuit, 4,800 volts, 3,000 and 7,200 alternations

Fig. 4 is similar to Fig. 3, except that the curves are for 25,000 volts and 3,000 alternations. In this figure the tendency of the curves to bend upward is much more marked than in Fig. 3. In other words, the limitation of the initial short-circuit current is much more necessary in high-tension circuits than in low-tension circuits.

On 25,000-volt circuits the non-arcing power drops still lower on account of the predominance of the inductance of the circuit and becomes nearly inversely proportional to the square of the initial current. The necessity of some resistance on such a circuit is very evident.

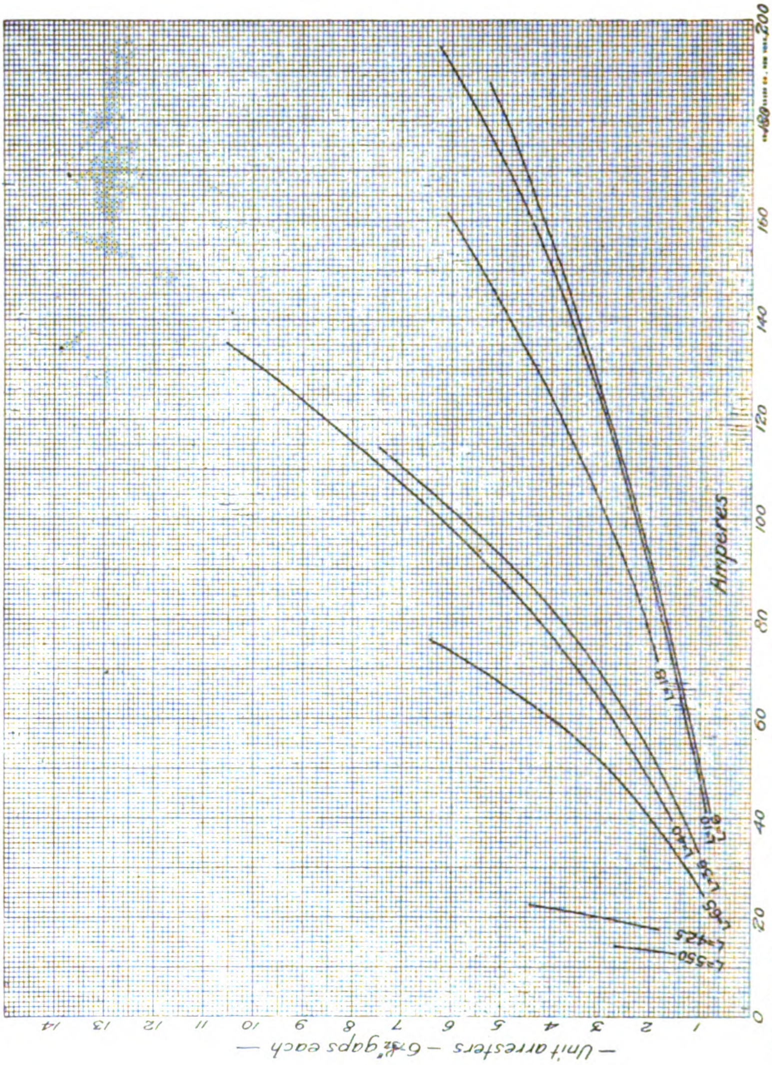

FIG. 3—Number of gaps necessary to suppress the generator arc with various initial short-circuit currents for different values of inductance in circuit, 12,500 volts, 3,000 alternations

Fig. 5 shows for different initial short-circuit currents in the series gaps of a combination of series and shunted gaps with shunt resistance, the number of ohms per shunted gap which will just cause a dropping out of the arc in the shunted gaps. It will be noted that this value varies enormously with the initial short-circuit current and that for currents over perhaps 200 amperes there is little or no shunting power for any useful value

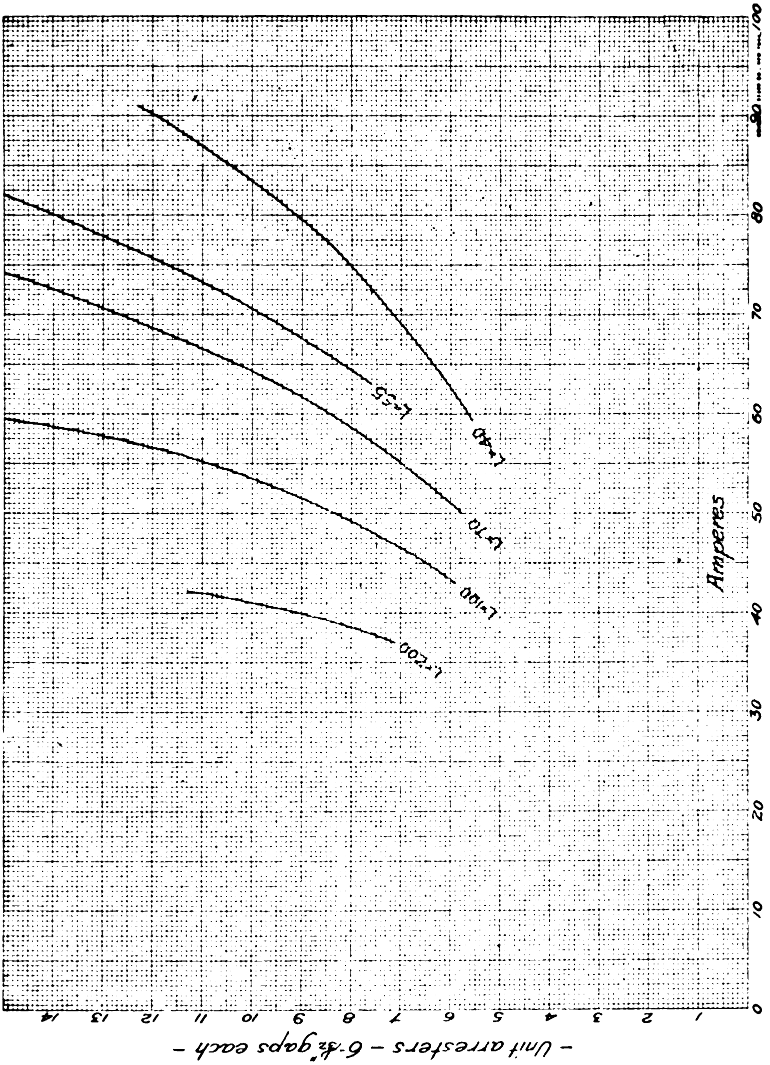

FIG. 4—Number of gaps necessary to suppress the generator arc with various initial short-circuit currents for different values of inductance in circuit, 25,000 volts, 3,000 alternations

of shunt resistance. The gaps are as before one-thirty-second of an inch, between Wurts's non-arcing metal knurled cylinders. The number of shunted gaps is always equal to the number of series gaps.

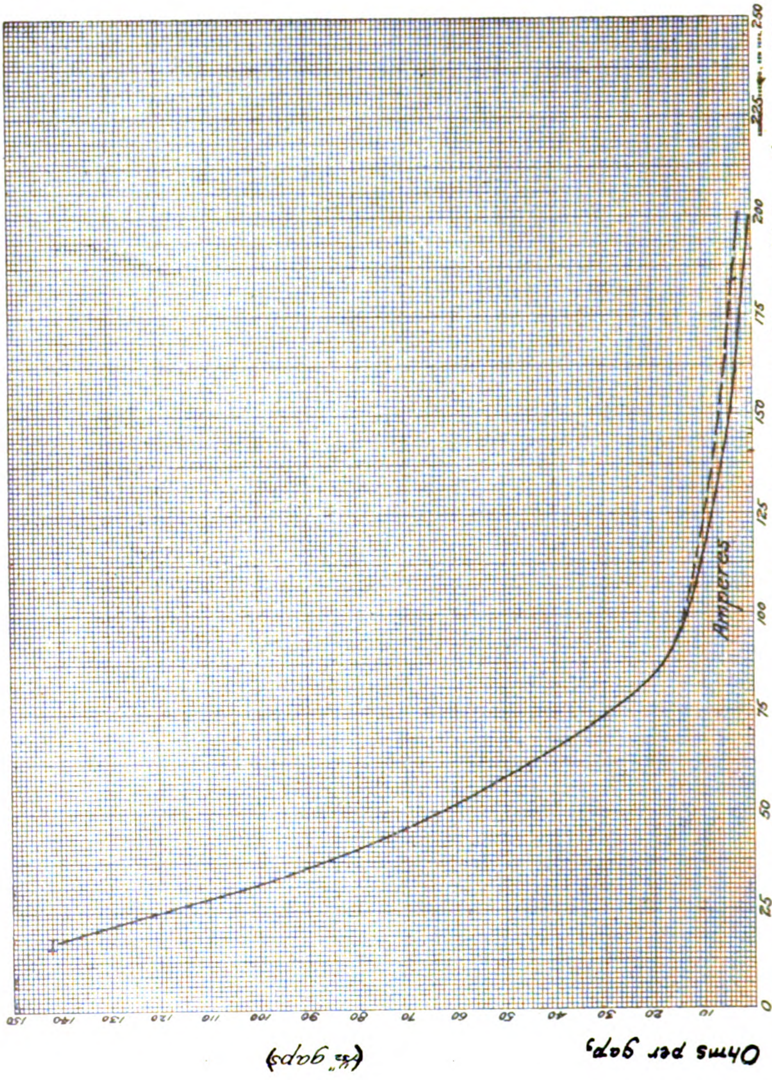

FIG. 5—Shunting power of shunt resistance. Maximum ohms per gap able to withdraw the generator arc from the shunted gaps with various initial short-circuit currents. Number of series gaps equals number of shunted gaps

For instance, with 25 amperes initial current a resistance of 120 ohms will just withdraw the current for the shunted gaps while with 175 amperes only from 2 to 5 ohms may be used, according to conditions.

The value of a given number of ohms per gap with a given short-circuit current is not entirely independent of the total voltage on the circuit of the inductance, etc., but is affected by these characteristics only to a minor degree. With high currents on low voltages, such as 2,500 volts, the shunting power is somewhat higher than with the higher voltages.

In estimates of the non-arcing power of arrester arrangements on various circuits, the initial short-circuit current is the dominating factor and the method of calculation becomes of importance. In these curves this current is calculated from the generated voltage of the supply, taking into account the total ohmic resistance in circuit, including rheostats, lines and armature windings, the inductance of all coils introduced, the inductance of the line and of the armature, together with the estimated field reaction of the current in each case. It is assumed that the resistance of the arresters during discharge was practically zero. This method is not absolutely accurate, partly because the gaps have some resistance and partly because an accurate determination of the armature impedance and field reaction of the generator is difficult to make, and for other reasons. But this method does give values of current dependent upon the essential determining factors and is undoubtedly sufficiently accurate for all practical purposes. Of course, in using the data of the curves for other circuits, calculations should be made according to the same methods.

Reference to the writer's original paper on this subject is suggested for a description of the method of the design of a non-arcing arrester for a given system from the basis of these curves.

A discussion of multiple shunt resistance will be found in papers by E. E. F. Creighton and by D. B. Rushmore and D. Dubois in Vol. XXVI of the Transactions of the American Institute of Electrical Engineers, 1907.

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25, 1907.

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A PROPOSED LIGHTNING-ARRESTER TEST

BY N. J. NEALL

It is generally recognized that the worst disturbances to an electrical transmission system from lightning are due to the unbalancing of the circuit-elements after the passage to ground of the initial lightning charge.

In the development of lightning-arresters provision must be made not only to discharge freely any atmospheric disturbances which take place near by, but to prevent as far as possible any short-circuit on the system which might thereby arise, should two legs of the line be simultaneously discharged. From this it follows that lightning-arresters in the very act of relieving the line, introduce other conditions of potentially great destructiveness, such as short-circuits, sudden grounds, and oscillations.

Since it is impossible to predict where any given lightning disturbance will arise on a transmission line, the assumption is made here that this is ordinarily of no consequence if it is not at the lightning protective apparatus. Any source of disturbance other than lightning which causes the lightning-arresters to operate may, however, properly be included here.

Fig. 1 shows the elements of the test. A spark from an induction-coil is made to pass over all the gaps of the lightning-arresters under test. This forms a bridge for either a short-circuit by line current (provided two legs of the line are simultaneously discharged) or for the passage of charging current from the stored capacity of the system, as the case may be.

The apparatus required consists of an induction-coil operated from several cells of a storage-battery by means of a mechanical vibrator. A small switch in series therewith enables the discharge to be controlled at will. A condenser is placed in series with each terminal of the induction-coil, the one being grounded and the other being led through spark-gaps to such a point of the series of the lightning-arrester gaps that the spark from the coil will divide and pass over them simultaneously in the direction of line and ground respectively.

Special gaps should be inserted in the induction-coil spark-circuit before connecting to the arrester under test to prevent a decrease in insulation strength to ground of the arrester itself.*

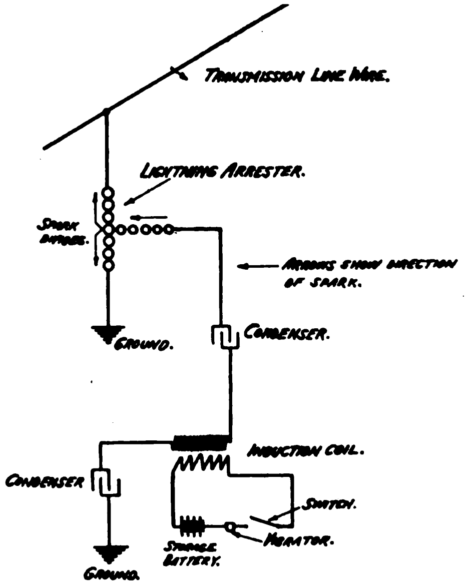

FIG. 1.
SHOWS PRINCIPLE OF TEST.

Figs. 2, 3, 4 and 5 are self-explanatory.

It will be seen from the diagrams that the required insulation strength of the condensers thus used in testing any polyphase system, is only half the nominal voltage between legs, for two condensers are always in series. Thus, for a test of a 50,000-volt line only 25,000-volt condensers are required.

With the exception of several laboratory tests, made first in

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*See Ingram, *Elec. Journal*—Vol. IV, No. 4.

Minneapolis in September 1906 on a 2300-volt circuit to prove the elements of the method, no trials have been made of this method on transmission lines. There is no apparent reason why it should not be used, save that when the possibilities of the method are realized, most transmission operators will undoubtedly be afraid to try it lest it may demonstrate itself too successfully.

There are undoubtedly plants in this country, and perhaps abroad, whose operators would be glad to avail themselves of any such method of generating their own "lightning"—to employ a late application of this term—and the ideas contained herein are therefore presented with the hope that they may pave the way to increased knowledge of lightning disturbances and protection against them.

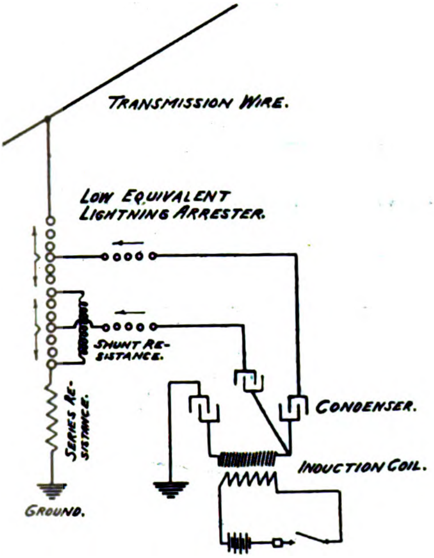

FIG. 2.

SHOWS SPECIAL APPLICATION OF PRINCIPLE TO LOW EQUIVALENT LIGHTNING ARRESTER FOR INITIAL DISCHARGE OVER ALL GAPS.

The following ideas have been suggested in this connection:

1. The apparatus must be adjusted in size and connection to individual requirements.

2. The effect of a disturbance can be measured positively by

the simultaneous use of tell-tale papers at all known points where discharges take place to ground.

3. The tests may be varied to suit any requirements; namely, short-circuits, grounding, phase to phase, etc., and may be made simultaneously at extreme points of a line with a duplicate test set if desired.

The following characteristics have been noted, and should be allowed for.

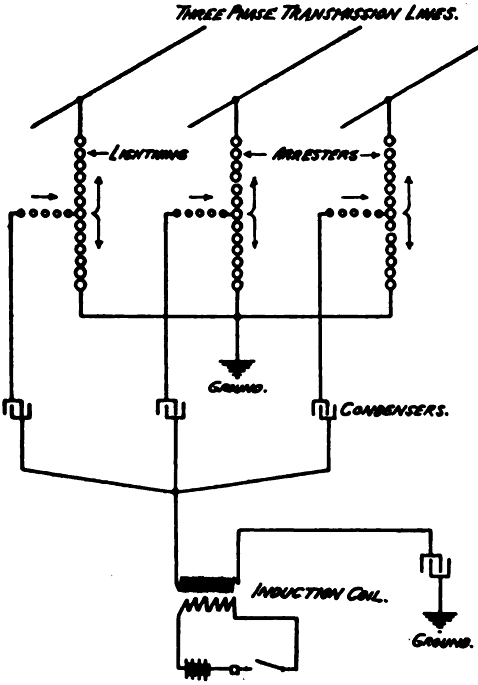

FIG. 3.
SHOWS METHOD OF CONNECTION FOR TESTING LIGHTNING ARRESTER GROUPS ON THREE PHASE SYSTEMS.

1. The coil must give a fat spark of considerable length. Such a coil as is used in wireless telegraphy is well suited to this.

2. The condensers need not be of great capacity. They may be of heavy glass coated with tin-foil and immersed in oil in stone jars.

3. There is apparently a definite limit to the number of gaps over which line voltage will break simultaneously with a given

static discharge. This has been noted in several cases and is quite marked. Any increase in the number of gaps, while apparently not affecting the spark, will prevent the arc.

4. Cells of storage battery permit the set to become portable, and thus enable field tests easily to be made.

5. The apparatus may be made quite rugged. In case of high voltage the exciting-circuit knife-switch may be opened and closed by an insulating handle to protect the operator against possible break-down of insulation between line and ground.

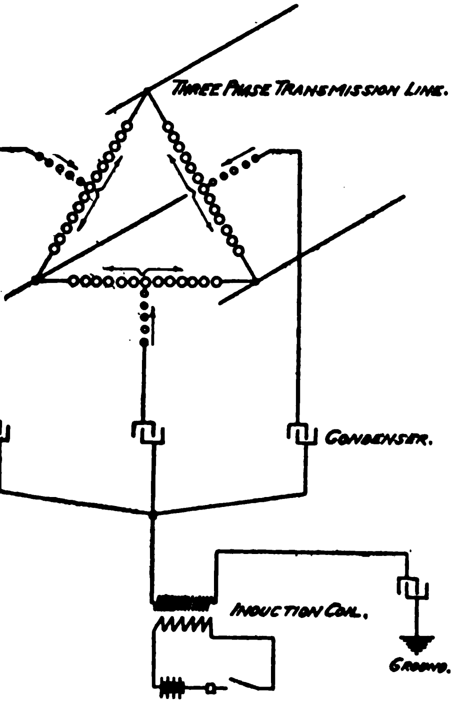

Fig. 4.
Shows a Suggested Method of Testing Phase to Phase.

6. The advantage in this method lies in its readiness for operation when required, its simplicity, and the fact that the induction-coil spark does not coat the cylinders or gaps with any metallic fumes.

7. It may be used for any lightning protective apparatus consisting of air-gaps between line and ground.

8. It is a method of as great value to the operator of the line as it is to the manufacturer of lightning-arresters, because it gives him the best possible method of determining how successful the lightning apparatus is in meeting the demands which he deliberately produces.

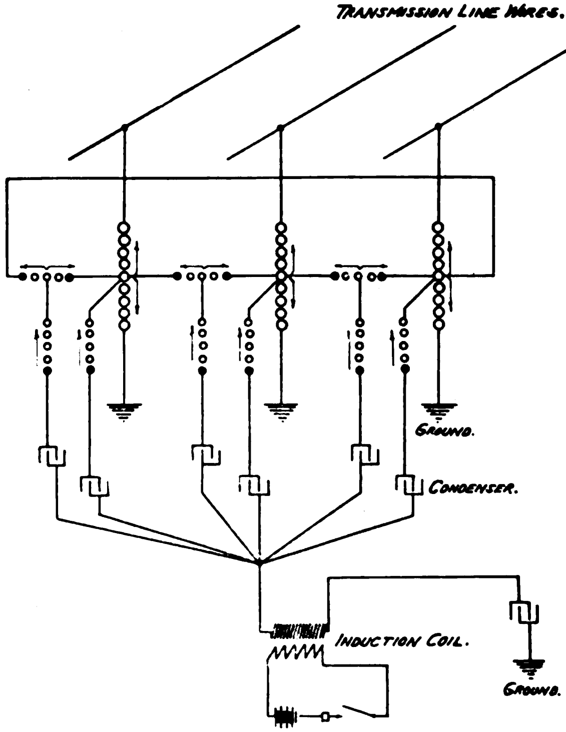

FIG. 5.

SHOWS A SUGGESTED METHOD OF TESTING THE MULTIPLEX PRINCIPLE ON A THREE PHASE SYSTEM.

9. Its intrinsic value rests on the importance of knowing as far as possible how great these disturbances may be, how efficient is any given system of protective apparatus to handle them, and of discovering to what degree any given transmission system contains in itself elements of length, arrangement and character of apparatus tending to prolong or increase the disturbances once initiated.

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26, 1907.

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NOTES ON TRANSFORMER TESTING

BY H. W. TOBEY

Transformer testing has already received a great deal of attention, and considering the number and variety of articles upon the subject which have appeared, the ground would seem to be quite thoroughly covered, so thoroughly in fact that there would at first sight appear little more to add. But in view of the changes which have been constantly taking place and the rapid advance in transformer design, a general discussion of the subject at this time may be of value. Experience also has led to the adoption of certain methods in commercial transformer testing which for various reasons have proved satisfactory, so that a description of these with their advantages and shortcomings will perhaps prove of some interest.

Present methods of testing, like many other methods, are the result of gradual but constant development, in which the good has been as far as possible retained and the poor eliminated and replaced with something better. What was suitable for small transformers, for example, was found to be entirely unsuitable for large sizes, and methods which applied very well to transformers of low voltage had to be modified or entirely abandoned for high-voltage apparatus.

Generally speaking, it may be said that tests are required for the purpose of determining the chief characteristics of the finished apparatus, thus enabling it to be compared with the original calculations and designs, and with the guarantee. They may be classified as follows:

Conversion.
Polarity.

Resistance.
Copper loss.
Core-loss and exciting current.
Regulation.
High potential.*
High voltage.*
Temperature rise.

Conversion. This test, while a comparatively simple one to make, is nevertheless extremely important, particularly where the transformers under consideration are intended for parallel operation or for delta connection to three-phase lines.

The most satisfactory method is without doubt one employing a standard multi-ratio transformer and a single voltmeter, provided the potential of the source of current supply does not fluctuate. Then, by applying a suitable common voltage to the high-tension side of the transformer under test and the standard, the two low-tension voltages may readily be compared and the true ratio obtained.

Where the supply is at all unsteady or where the ratio of the standard varies considerably from that of the transformer under test, the two-voltmeter method is preferable. Accurate results may then be obtained by taking two sets of simultaneous readings, between which the instruments are interchanged to eliminate any dissimilarity between them.

The opposition method is also sometimes used to good advantage. With this, however, care should be used to see that the low-tension voltage of the standard and of the transformer under test are exactly in phase.

As an additional precaution, single-phase transformers which are required to operate in parallel on single-phase circuits, or delta on three-phase circuits, also delta-connected phases in three-phase transformers, should be connected as they are eventually intended to operate, and a test made for circulating current. This serves as a check on conversion measurements and is important from the fact that a slight difference in voltage between windings is apt to lead to serious results.

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*Both of these are essentially insulation tests. The terms "high potential" and "high voltage" are used arbitrarily to distinguish between a test applied between primary and secondary windings and iron, and one applied across terminals of the same winding. The first tests the strength of the insulating barriers and casing, while the second tests the insulation between turns and between layers.

Polarity. The relative position of primary and secondary leads is ordinarily determined either by direct comparison with a standard transformer or by applying direct current to the high-tension winding, noting the position of positive and negative connections by means of a direct-current voltmeter, then shifting the voltmeter leads to the low-tension winding and noting the voltmeter deflection upon breaking the direct-current circuit. When testing large numbers of small transformers having approximately the same voltage and ratio, the first method is quicker and more satisfactory. For power transformers having as a rule widely differing voltage, the second method is usually preferable.

Resistance and Copper Loss. In the measurement of resistance for the determination of copper loss and total resistance drop, the fall of potential method gives in general the most satisfactory results of any of the standard methods. The instruments required are less delicate than the galvanometer used in bridge measurements, may be readily calibrated, and will give accurate results over a wide range.

When measuring resistances of small transformer windings, the instruments come to rest very quickly and little time is required for taking the readings. With large transformers, however, unless special precautions are taken, this is seldom true; for even with the terminals of the opposite winding short-circuited on themselves, some seconds, or even several minutes, often elapse before the instruments settle, so to speak, to a final value, and until this settling has stopped, readings will not indicate the true resistance.

Fortunately, this condition of affairs may be overcome by forcing through the winding under test a direct current of ten or twelve times that finally required for the measurement, and after a moment or two dropping it to normal before taking the reading. (Of course during the passage of this increased current the voltmeter should be disconnected and the ammeter short-circuiting switch closed.)

While a delay of a few seconds or several minutes may do no particular harm at the time when cold-resistance measurements are made, it is extremely annoying during heat runs where measurements are taken at frequent intervals. Long interruptions of the load under these conditions are apt seriously to affect the final temperature.

Core-Loss and Exciting Current. The influence of wave-form upon core-loss and exciting current has already been carefully investigated, and the importance of using a sine-wave source of current supply is well known. It is doubtful, though, if all fully realize how far from a sine wave the electromotive force of some generators really is under actual conditions of test; that is, when supplying core loss to transformers. This may occur, even though the wave-form of the generator is entirely satisfactory under normal conditions, from the fact that the wave becomes badly distorted at low power-factors which occur when transformers, particularly those designed for low frequencies, are operated on open circuit. The extent to which this distortion may reach, and its effect on core-loss and exciting current are clearly indicated in the accompanying curves and data which follow.

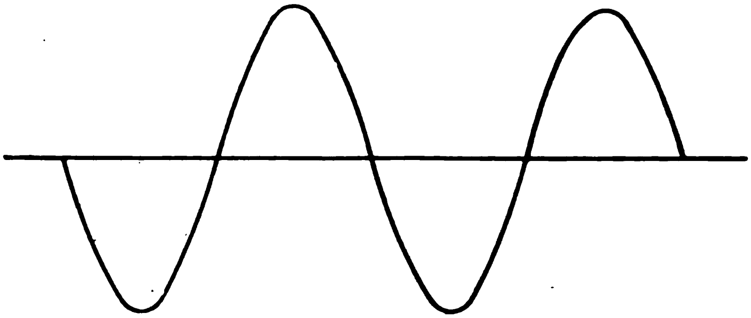

FIG. 1

The curve, Fig. 1, was taken on one of the generators in question while on open circuit. The curve, Fig. 2, was taken on the same machine while furnishing core-loss and exciting current to a transformer. It will be noted that both approximate very closely a sine wave. The oscillograph curve shown in Fig. 3 was taken while a generator, having a very peaked wave, was exciting the same transformer at the same voltage. The resulting core-loss and exciting-current measurements are given as follows:

First case; sine wave, core-loss 1177 watts, current 33.5 amperes.

Second case; peaked wave, core loss 924 watts, current 15.4 amperes.

By comparing these sets of readings it will be seen that in changing the source of supply from one, giving very nearly a sine electromotive force wave, to one giving a peaked wave, the core-loss decreased to 79% and the exciting current to 44% of the original values.

Another transformer measured under conditions shown in Fig. 3, and again under conditions indicated by Fig. 4. required respectively 5500 and 7325 watts core-loss and 25.3 and 47 amperes exciting current, an increase of 33% and 87% respectively. These readings show the variations which may occur with peaked waves of the same general character.

These figures clearly indicate the importance of referring all measurements to a standard form of wave. At first sight the peaked wave would seem to have some advantages over the sine wave, owing to the lower core-loss and exciting current values which result. After all sides of the question are considered, however, including among other things the effect of wave-shape on insulation strains, etc., a sine-wave electromotive force is undoubtedly the best. And what is equally important, the generator from which the supply is obtained should not only maintain the standard form on open circuit and on non-inductive loads, but also on low power-factor inductive loads; *i.e.*, *under the conditions of test.*

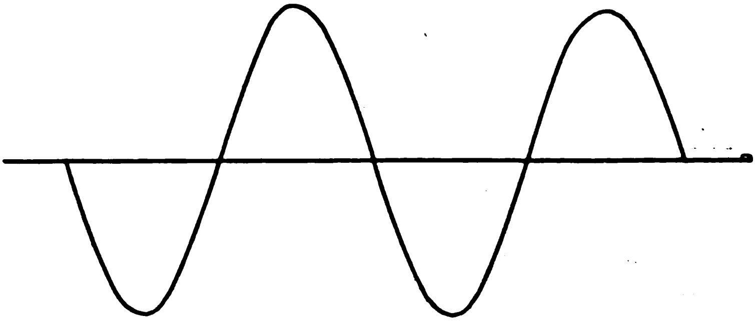

FIG. 2

In the measurement of core-loss on three-phase transformers the windings across which the readings are taken should be Y connected and the opposite windings left open in case they are intended for delta connection. Otherwise the circulating current due to unequal distribution of flux in the core and to the short-circuiting of the odd harmonics will show up as an increase in core-loss, thus giving incorrect results. In case the transformer windings on one side are delta connected, and for any reason cannot be changed, it is preferable to connect both sides in delta before taking the core-loss measurement. The resulting circulating current will then occur in two windings instead of one, and being proportionally less, will produce smaller disturbing losses in the copper than if but one winding alone is delta connected.

Regulation. In general, it is now customary to determine the regulation of a transformer by one of the several methods which require impedance measurements with one of the windings short-circuited on itself, this having entirely superseded the old way of measuring the voltage with transformer free and loaded.

Here, too, it is important to employ a generator which will give a sine wave at low power-factor loads, for while it is true that the wave-shape does not affect the measurements so seriously as those mentioned under the preceding heading, nevertheless the variation is fairly well marked.

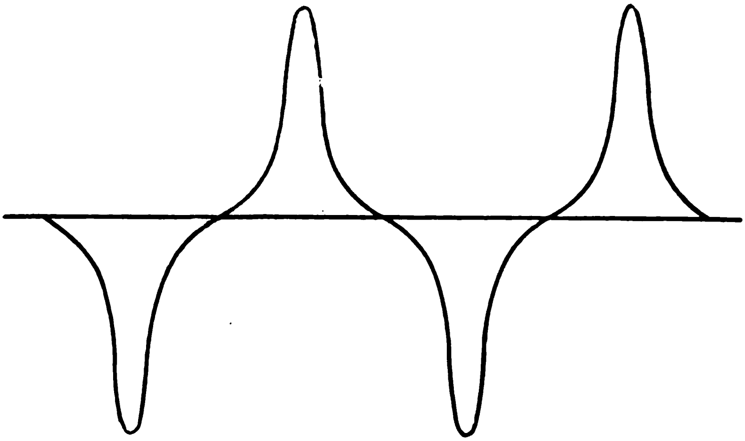

FIG. 3

High-Potential Test. On low-voltage transformers this test is not a difficult one to apply correctly, but where the voltage is high the question is entirely different, and the chance for error is large. This is chiefly because of the absence of a suitable means of measuring high potential. To be sure, either the conversion method or the spark-gap method may be used, though both are open to criticism. Individual conditions alone can determine which is most suitable.

If the testing transformer has extremely close inherent regulation, and the charging current under conditions of test is but a small proportion of its normal current capacity, it is reasonably safe to rely upon multiplied by the low-tension voltmeter reading, and to consider that this times the ratio of conversion is an approximate indication of the high-tension voltage. If these conditions do not exist, the spark-gap method must be relied upon. It should be used, however, with great care.

As the conditions under which the testing outfit operate are changed entirely by the introduction of the transformer under test, it is obviously not right to measure the high-tension voltage by spark-gap before this transformer is connected. On the other hand, if the transformer is connected in, together with the properly adjusted spark-gap, and the voltage is raised until the latter arcs over, high-frequency oscillations almost invariably occur and result in a rise in voltage. The final value of this voltage may be considerably higher than that required, resulting possibly in an uncalled-for break-down of insulation.

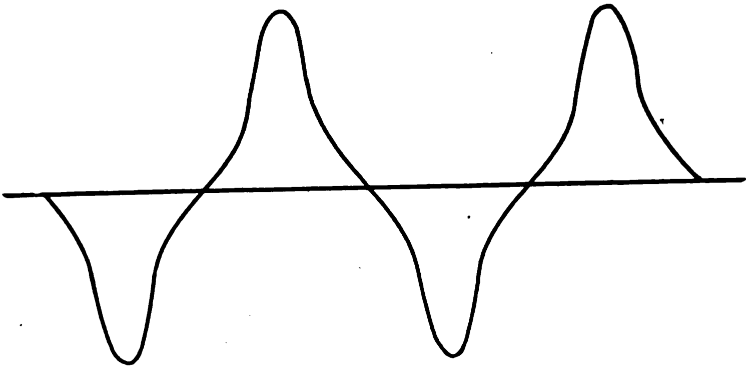

FIG. 4

Such a disturbance may be overcome in one of two ways, both of which have been tried with satisfactory results. The first consists of inserting in series with the gap a high resistance,* the presence of which prevents the occurrence of a high-frequency disturbance when the spark-gap breaks down. The only precaution necessary in the use of this auxiliary resistance is the calibration of the spark-gap with the resistance in series, as its presence will in general increase the effective value of the gap. In other words, the distance between needle-points, as given in the standard Institute table, may need to be decreased by from 5% to 10% to obtain correct results.

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*For potentials ranging from 100,000 to 200,000 volts, a resistance consisting of a dozen U-shaped glass tubes one-half inch inside diameter and two feet in length will be found satisfactory. These should be mounted in a suitable rack, filled with water and connected in series.

The other method referred to above, consists in making all connections for the high-potential test and placing the spark-gap across the circuit, the gap previously having been set, however, for a somewhat lower voltage than that required, two-thirds for example. The voltage is then increased, and the low-tension voltmeter reading is noted at the moment the spark-gap breaks. The gap is now disconnected and the electromotive force again raised until the voltmeter reading, in the case cited, is 50% greater than before. The desired potential is thus obtained with fair accuracy without any disturbance in the circuit.

The importance of using a sine-wave generator for supplying current to the testing transformer is hardly to be questioned. Otherwise, it will be extremely difficult to obtain the desired testing strain.

As to varying the voltage of the high-potential transformer, several methods are possible, including the use of a variable resistance, a variable reactance, or changing the excitation of the generator field. The first, except perhaps in the case of low-voltage tests on small apparatus, should not be resorted to, as it has a very disturbing effect on the wave-form. The second gives more satisfactory results in this respect, and serves very well when the required range is not too great. In general, the last method; which is that of varying the generator-field excitation, is perhaps more often used, chiefly because it enables the voltage to be varied gradually over a wide range. Low field-densities, however, are apt to lead to armature reaction if the machine is furnishing anything like full-load current, so that even with this method some distortion of wave-form may result.

A discussion of this branch of the subject would hardly be complete without some reference to the effect which the time of application of the high potential has on the resisting strength of insulation. In other words, if an insulating material will safely withstand 50,000 volts for one minute, what potential will it withstand if the test is continued for five minutes and what will it resist indefinitely?

This relation between time and voltage is fairly well represented by the curve shown in Fig. 5. This was obtained from a series of tests on sheet insulation, potential from a 60-cycle sine-wave generator being applied to two brass discs arranged on opposite sides of the test piece.

It will be noted that for periods of one minute the sample safely withstood a pressure of 65,000 volts. For five-minute tests it was necessary to lower the pressure to about 70% of this value, or 46,000 volts; while in order to resist the test indefinitely, the applied voltage had again to be lowered to 27,500 or about 40% of its original value.

These figures can hardly be taken as general, for they change considerably with different kinds of insulation and the resulting curves assume widely varying forms. In most cases the reduction in strength as the length of the test increases, is much less than indicated above, so that in comparing the instantaneous test and continuous test, for example, the reduction is nearer 50% or 60% instead of 70% as in the sample noted. These figures serve to emphasize, nevertheless, the undesirability of long-continued strains, and tend to confirm the advisability of retaining the present one-minute standard.

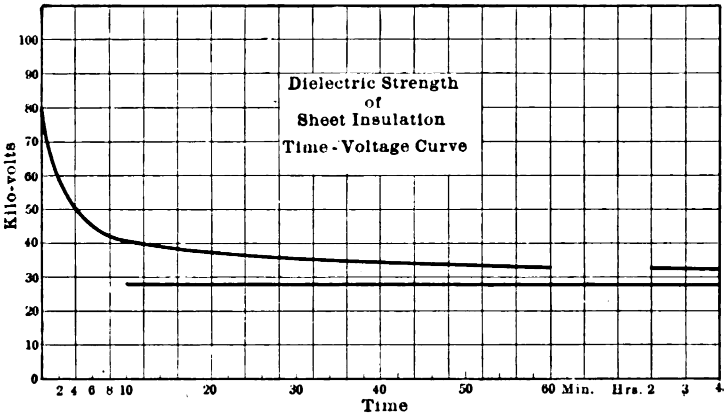

FIG. 5

High-Voltage Tests. The test which determines the strength of insulation between turns, between layers, and between leads, is equally as important as the "high-potential" test just referred to. If the transformer windings withstand double voltage, or, in the case of lightning transformers, triple voltage, their internal condition is reasonably well assured.

In applying this test it is usually advisable, and in most cases necessary, to use a frequency considerably higher than that for which the transformer was designed; otherwise the exciting current will become so excessive as to make it difficult or even impossible to obtain the desired increase in voltage.

In general, satisfactory results are obtained by employing a frequency as much above that for which the apparatus is designed as the test voltage is above normal terminal voltage. With a 60-cycle transformer under consideration, for example, 120-cycle current gives good results for double voltage tests, while 180 cycles is usually satisfactory for triple voltage. A 180- to 200-cycle generator answers very well therefore in the majority of instances.

Temperature Tests. Except perhaps in the case of special tests on small transformers, or where a single transformer is to be tested, the differential method of applying load for the temperature test or heat run is the most satisfactory and probably the one most universally used. This ensures very nearly the conditions of actual operation, enables the work to be carried on with a minimum waste of power, and requires a comparatively small amount of auxiliary apparatus. The total losses occurring are in general somewhat in excess of those which would take place if the transformer were normally excited and loaded on a dead resistance, or, if it were operating under actual conditions of service, therefore the results are always on the safe side.

While it is perhaps preferable to make this run at normal frequency, both on the exciting and loading side, still this is not absolutely essential to satisfactory results. In fact, two entirely different frequencies may be employed if desired, it merely being necessary to adjust the exciting voltage so as to obtain what has already been found to be the true core-loss at normal frequency and then to feed the required current into the other side. (By normal frequency is meant the frequency at which the apparatus is intended to operate).

The resistance readings taken at intervals during the run for the purpose of temperature determinations should obviously be made with the shortest possible delay in view of the necessary removal of load at such times. It is here, therefore, that the precaution mentioned under the subject of " Resistance and Copper Loss " is most useful. By observing this, and by employing a suitable arrangement of double-throw switches to which the measuring instruments and source of direct-current supply may be permanently connected, the time required to take a resistance reading is reduced to a minimum.

General. The order in which tests should be made, depends more or less upon local conditions, so that no fixed rule can be given, nor, in fact, is one necessary. The general order in which the tests have here been described is perhaps as good as any. It has the advantage of placing the heat run at the end, so that in case any part of the insulation has been injured by previous tests, the fault will become evident while the transformer is under load and operating under service conditions. It is sometimes considered advisable, however, after the heat run has been finished, to repeat the measurements of core-loss and exciting current. Any defect in the winding will then be apparent at once.

The question of instruments with which to carry on the various tests has not been touched upon, for this forms a complete subject in itself. It is needless to say that the selection of instruments should be made with the utmost care, as on their construction and accuracy depends the value of the tests.

Not only should they be selected carefully, but the same care should be exercised in their handling and use, and frequent calibrations, at least as often as once a week, should be the rule.

Testing as a whole requires painstaking and constant study, and changing conditions of design and construction must be carefully followed if it is to fulfil its purpose.

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26, 1907.

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A NEW TYPE OF INSULATOR FOR HIGH-TENSION TRANSMISSION LINES

BY E. M. HEWLETT

LINK INSULATORS. SUSPENSION AND STRAIN TYPE.

The transmission of large amounts of power over long distances has reached such proportions that the voltage necessary to transmit this energy makes the problem of line insulation difficult. The so-called "pin" type of insulator has been enlarged to meet the greater demands until it has approached, if not already passed, the limits of good construction. Mr. Buck has given this matter a great deal of study in his high-potential transmission work, and being dissatisfied with the mechanical features of a pin insulator, has devised a method of line construction involving the use of "suspension" and "strain" insulators. The suspension insulators support the line from above, hanging vertically beneath the cross-arm (or other point of suspension). The strain insulators are used at turns and at intervals of say, every mile, to support and "anchor" the line, also as pull-off insulators on curves and to dead-end lines.

It is intended in this paper to give some mechanical and electrical tests and describe a porcelain insulator which the writer has designed to carry out this method of supporting of high-potential transmission lines.

Each insulator unit is a flanged or petticoated disc with an enlarged central portion having two interlinked semicircular holes. It is called a "*link insulator*" because it is used to insulate the interlinked tie-wires. The holes in the insulator are so arranged that the tie-wires which pass through them exer a compression strain on the porcelain (Fig. 4). Should the insulator

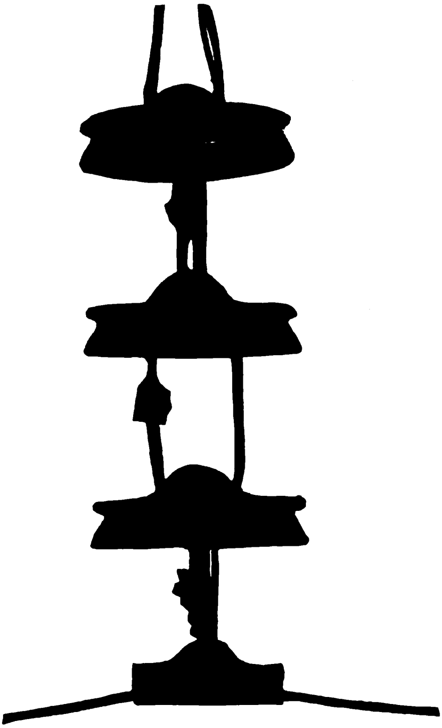

Fig. 1

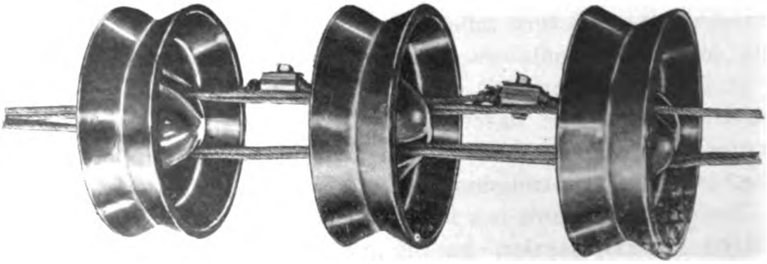

Fig. 2

break, the tie-wire loops will still be intermeshed (Fig. 5), and as the discs are used in series, with a factor of safety, the remaining discs prevent a ground being formed until the break can be repaired. The link insulator for suspension (shown in Fig. 1) is a petticoated disc, while the strain insulator (Fig. 2) is a disc with a grooved flange. The mechanical and electrical features of the two forms of insulator are essentially the same. The petticoats and flanges are so arranged that one side of the insulator is always protected from rain.

A diameter of 10 in. for both types of insulators has been found by experiment to be most convenient, and such insulators are suitable for a working voltage of 25,000 volts per disc. For higher potentials the discs are placed in series; for instance four 10-in. discs would be suitable for a 100,000 volt line. As the separate discs arc when wet at approximately 65,000 volts, the rated voltage of 25,000 volt is within safe limits. The 10-in. discs were tested for strength and supported a load of three tons.

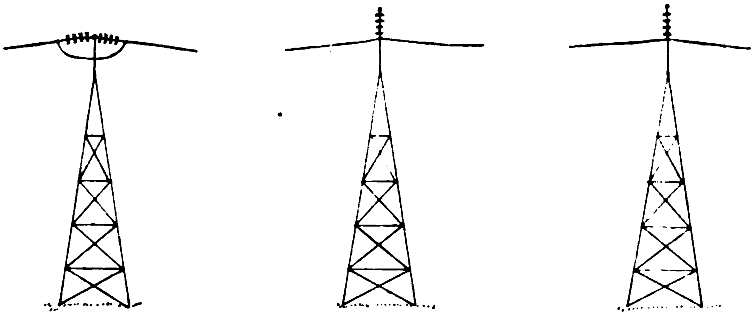

FIG. 3

The insulators described above being made of one piece of porcelain, no cemented fittings or sections are necessary. They are not affected by extreme heat or cold, having stood the test of a severe winter. Tests prove that insulators with sheltered surfaces stand a much higher rain test than a much larger insulator which has no dry surface, as for example, a flat disc without the flange or petticoat.

Fig. 3 shows a possible method of line support using ten towers per mile, in which the line is anchored at the end of each mile and at curves, and suspended at intermediate towers. From the cut it will be noted that the conductor is looped around

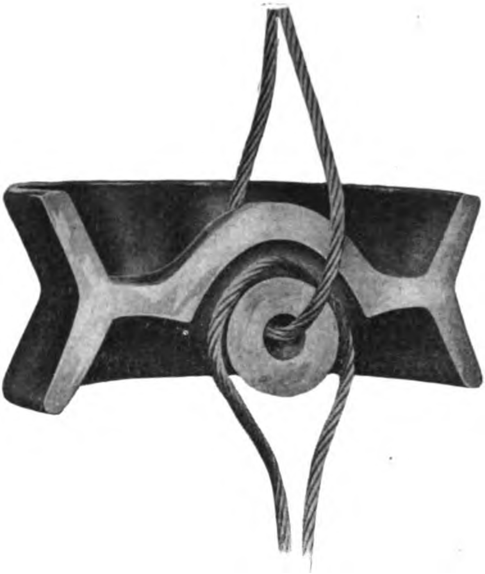

Fig. 4

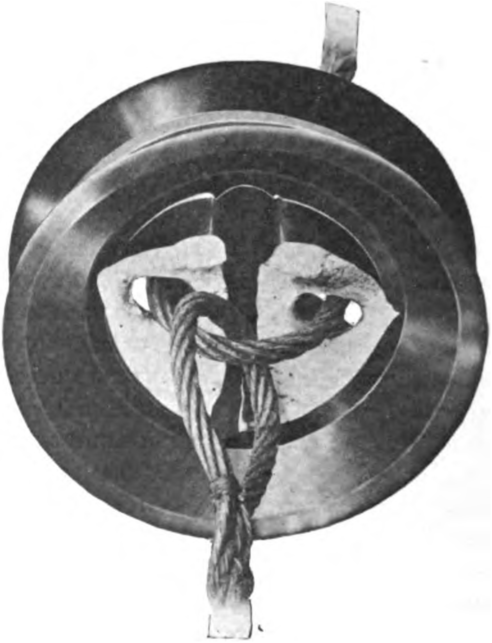

Fig. 5

the strain links at the anchorage towers. The use of this type of insulator does away with torsional strain on the cross-arms, giving it a decided advantage over the pin insulator. It is obvious that the link insulator is adaptable to a great variety of conditions.

Fittings have been designed for use with these insulators to fit the conditions thus far presented, but each case should be considered as it comes up, and such fittings designed as are necessary.

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26, 1907.

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SOME NEW METHODS IN HIGH-TENSION LINE CONSTRUCTION.

BY H. W. BUCK.

The great economies in the cost of generating power which have been obtained in the large steam turbine stations and hydroelectric plants, are leading to the general abandonment of small generating stations and the increase in transmission distances in order to distribute power over a large territory. In other words, 100,000 h.p. can be generated in one station and transmitted 100 miles cheaper than it can be generated and distributed from ten 10,000-h.p. stations near the center of load. On account of this tendency toward the concentration of generating units, the overhead transmission line has assumed a position of great importance in electrical installations, and the same permanency and reliability is demanded of it as of the generating station itself. The wooden pole line of the past has been practically abandoned and steel construction has been substituted.

The long distances covered by many of the modern lines, the large amounts of power to be transmitted, and the very high price of copper and aluminum—all have combined to force up the transmission voltage to the highest practicable limit. In consequence the demand for high-voltage overhead line insulators has outgrown the present standard practice, and some new systems will have to be introduced to meet the new conditions.

The method of line construction here described has been developed by the writer and Mr. E. M. Hewlett and is believed to offer a means of operating lines safely at higher potentials than is practicable with insulators of the pin and petticoat type.

Fig. 1 illustrates in a diagrammatic way the arrangements for one circuit. The tower supports shown here are those which were used merely for experimental work and need not be considered as a commercial design. Each span is dead-ended at each support as shown, through a series of insulating units which in this case are plain discs connected together with steel links. The various spans are then electrically connected by jumpers hung below the insulators. The insulators are directly attached to the cross-arms, eliminating all pins. The number of discs linked together in series depends upon the line voltage, the discs themselves being identical for all voltages.

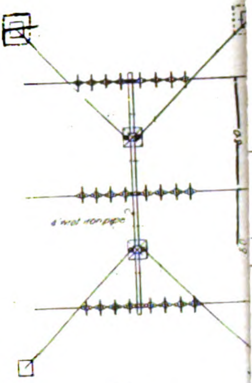
Fig. 2 illustrates a design for a 100,000-volt two-circuit line which is soon to be constructed for transmitting 50,000 h.p. 165 miles. The spans in this case will range from 500 to 1000 ft. in length. Here the line is suspended below the cross-arm on most of the towers. The lines will be dead-ended with jumper connection as shown only at angles and on tangents at about every fifth tower. This dead-ending will be for the purpose of stopping any creeping of conductors on the line as a whole, to check the transmission of longitudinal waves along the conductors due to wind, and on curves to take the side stress of the conductor due to change in direction. In this installation the lines will not be triangulated, but at suitable intervals along the lines the conductors will be transposed so as to balance up effects of mutual static and magnetic induction. Special cross-arms will be installed at transposition towers.

Fig. 3 illustrates another design for a two-circuit line which is to be built for 80,000-volt operation. The spans in this case will range from 300 to 400 ft. and the conductors will have an approximate triangular relation. The conductors will be suspended by a series of insulators from the cross-arms as in Fig. 2 with occasional rigid attachment, for the reasons given above.

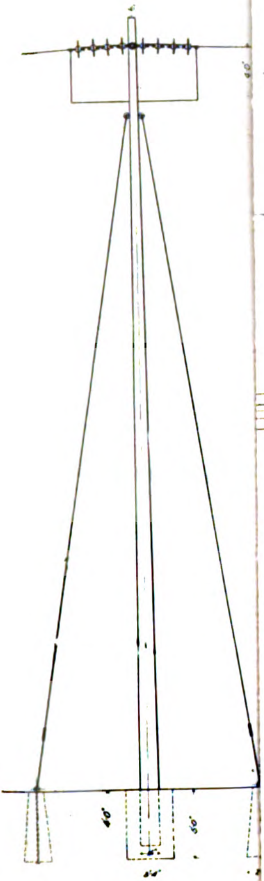
Fig. 4 shows a method of assembly of the insulators for suspension under a cross-arm. Fig. 5 illustrates a method of assembly where spans are dead-ended at the cross-arm with jumper connection.

The advantages of this construction, which might be termed "series unit insulation," over the pin and petticoat type may be summarized as follows:

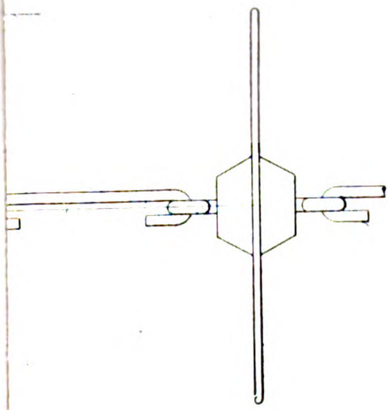
a With the standard type of pin insulator now used the difficulties of construction increase very rapidly at the higher voltages. The cost of insulator for a given margin of safety increases for



Plan



Side Elevation



voltages above 60,000 nearly as the cube of the increase in voltage. Either very large petticoat diameters must be used, or

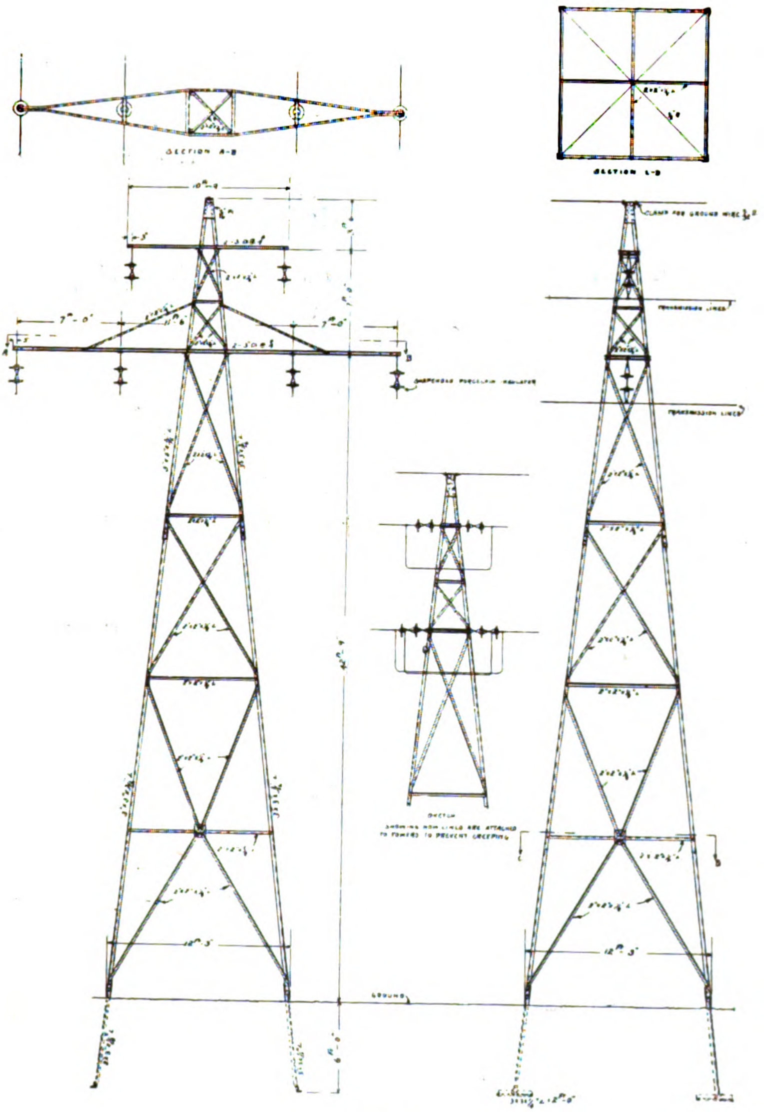


FIG. 2

very high insulators with many petticoats. In either case the manufacture of the porcelain parts is a difficult and expensive matter, and with the long pin necessary, the mechanical stresses from the line on insulator, pin, and cross-arm are objectionable. With the series unit system here proposed, the cost of insulator progresses only in direct proportion to the increase in voltage, the only change being in the number of units in series. There is practically no limit to the degree of insulation obtainable.

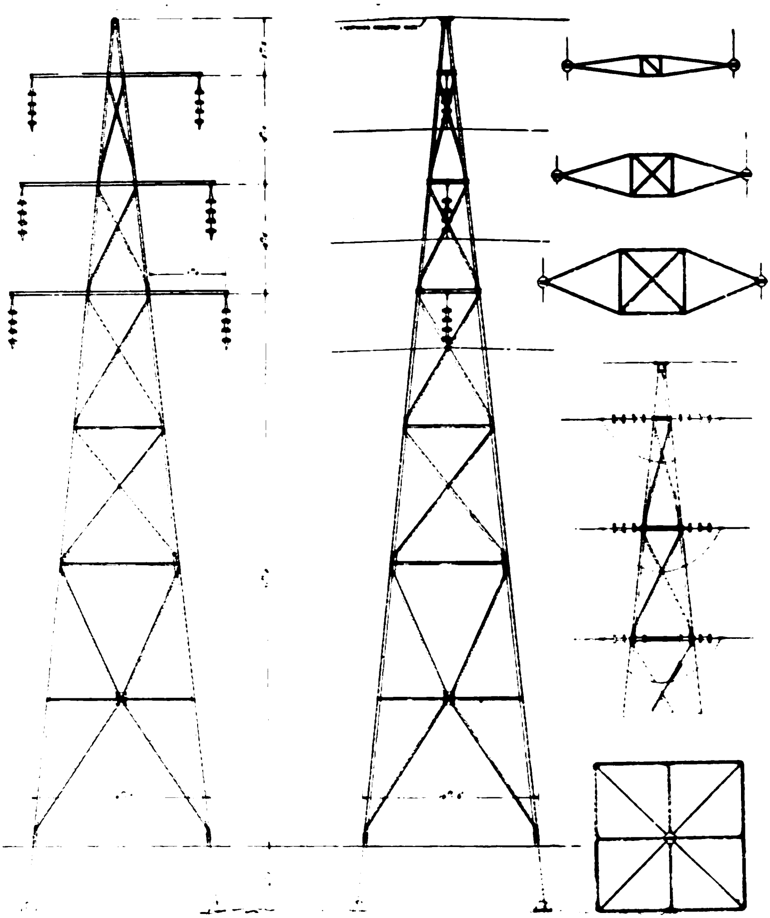


FIG. 3

b One of the most difficult elements of design in a transmission tower where long pins and petticoat insulators are used, is to obtain a cross-arm which will resist the torsional stresses due to the leverage of the pin. With the pin entirely eliminated, the stresses are directly applied to the cross-arm; this cheapens the construction of the tower.

c In the arrangements shown where the insulating units are attached on either side of the cross-arm, taking the full tension in the line with jumper connection between spans, the insulation can be increased indefinitely by adding discs in series without increasing the space occupied on the tower.

d Where each span is dead-ended, as in (*c*), all faces of the insulating units are exposed to the cleansing action of the rain, so that dirt cannot accumulate thereon. This arrangement also prevents the dripping water from forming electrical communication between units as occurs from one petticoat to another in the pin type of insulator.

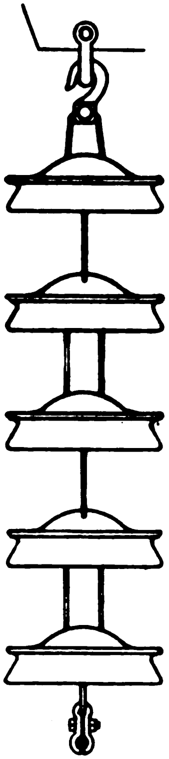


FIG. 4

e A standard insulating unit can be adopted for all voltages, the only variation being in the number linked in series. This simplifies the manufacturing problem.

f If any insulating unit becomes damaged or completely shattered, the insulation of the remainder is not affected. The damaged unit can be replaced without the necessity of renewing the whole.

g If a tower is directly struck by lightning the cross-arms will be likely to take the discharge, since they are above the lines, whereas in the pin type of insulator the line is usually the highest point.

h In long-span installations where the conductor at each end of the span is tied fast to an insulator mounted on a pin, experience has shown that crystallization is apt to take place in the conductor at the tie, due to its rigidity at that point and the vibrations in the span. This frequently results in breakage of the conductor. The flexible connection between conductor and cross-arm afforded by the series of insulators should reduce this tendency to crystallization, and should therefore permit spans of any length to be used without further precautions against this action.

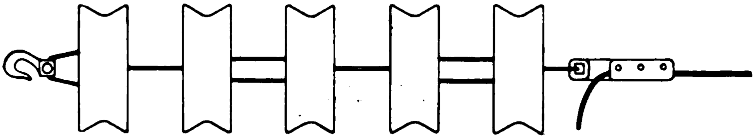


FIG. 5

Fears may be expressed that with the conductor suspended under the cross-arm serious swinging to and fro might take place. From numerous observations it is believed that no such swinging will occur. Long aerial spans under wind pressure take a permanent and steady deflection throughout the span proportional to the average wind velocity along the span, and no indications have been observed of long spans responding to so-called gusts. The towers shown in this paper are designed so that the conductor can safely be deflected by the wind about 60° on either side of the neutral position.

Insulators of a great many forms have been built and tested, but the one which gives the best results electrically and mechanically is the link type developed by Mr. Hewlett and having the grooved or fish-tail periphery. Four of these in series is sufficient for 100,000-volt operation with a liberal factor of safety.

A very important element in this construction is of course the methods of fastening the insulating units together and attaching them to the line and cross-arms. This can be accomplished in many ways and several methods have already been worked out, but these details are beyond the scope of this paper. Further experience in practical line construction and operation under this system will demonstrate the best methods of installation and attachment.

A paper presented at the 24th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26, 1907.

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SWITCHBOARD PRACTICE FOR VOLTAGES OF 60,000 AND UPWARDS

BY STEPHEN Q. HAYES

The idea of this paper is to touch briefly on the salient points of interest in connection with high-voltage switching practice and if possible to bring out in the discussion the opinions of various engineers interested in this line of work, relative to such points as have not been definitely settled by standard practice as being the best solution of the problem.

The reason for limiting this paper to voltages of 60,000 and upwards is that while the design of stations for voltages up to 60,000 has often been described but little has been written regarding any for higher pressures. It might be remarked, however, that the switchboard practice for these higher pressures does not differ very materially from that found desirable for voltages from 33,000 to 60,000. In fact 33,000 volts seems to be the critical point at which it is found advisable to change the type of switching devices, wiring, etc., and most of the remarks in this paper would apply for any installation above 33,000 volts.

In comparing the merits of different types of apparatus, the relative advantages and disadvantages of the conflicting designs have been stated in a manner as free as possible from bias, but the statements are of course the personal opinions of the writer and consequently are open to criticism from others having a different point of view.

The matter of suitable switchboard equipment for any plant may be briefly summarized as follows:

I. *General Scheme of Connections.* Under this heading it is necessary briefly to consider the following matters:

a. Type of plant.

b. Frequency.
c. Transformers.
d. Flexibility versus simplicity.
e. Main connections.

II. *Necessary equipment.* Under this heading should be weighed the relative advantages of the following:

a. Switchboards, panel type.
b. Switchboards, pedestal type.
c. Switchboards, desk or bench-board type.
d. Types of oil circuit-breakers.
e. Types of disconnecting-switches.
f. Types of protective apparatus.
g. Bus-bars and wiring enclosed.
h. Bus-bars and wiring open.

III. *Present design.*

a. Typical station for 60,000 volts.
b. Typical station for 100,000 volts.

IV. *Future design.*

a. Indoor transformer and switching stations.
b. Outdoor transformer and switching stations.

I-*a.* *Type of plant.* Without exception, in America plants operated at or designed for voltages of 60,000 or higher employ three-phase circuits and obtain the high voltage by means of transformers. For this reason this is the only type of plant which will be considered in this paper as being of practical interest at present.

I-*b.* *Frequency.* Nearly all the important transmission systems operate at frequencies of 25 or 60 cycles, although frequencies between these limits are used in Mexico and elsewhere, and a lower frequency has been suggested for large railway work. The switching equipment, however, being independent of the frequency, it is unnecessary to consider this matter here.

I-*c.* *Transformers.* For plants of the type considered in this paper the transformers are invariably oil-insulated and usually water-cooled, and may be built either in single-phase or three-phase units and connected in delta or star. With delta connections it is often desirable to cut out any one transformer, leaving the remaining two connected in *V*; knife-switches or oil circuit-breakers are sometimes supplied for this purpose in addition to the other switches or breakers that would normally be used.

With star connections, if the neutral is grounded, it is often feasible to use smaller switches, breakers, etc., owing to the lower insulation strain. By connecting the instrument series transformers at this neutral point instead of in the main leads a cheaper and better arrangement for supplying current to the meters or relays can often be made. The relative advantages of delta or star connections, being a question of transformers and not of switchboards, will not be taken up in this paper.

I-*d. Flexibility versus simplicity.* In settling on the design of a power plant, it is necessary for the engineer to consider carefully the relative importance of flexibility and simplicity and to determine the relative value of apparatus needed only in emergencies and the saving resulting from its omission. While it is possible to duplicate the equipment of switches, bus-bars, etc., so as to take care of almost every contingency or to reduce the equipment so that trouble in one or two places may seriously cut down the output of the plant, a happy medium can usually be found.

Although the conditions of each plant have to be carefully examined, and due consideration given to the nature of the load, capacity of station both for initial and ultimate installation, sizes of generator, and transformer units available, the general problem for all plants is to obtain the maximum amount of flexibility and safety with the minimum cost of apparatus and building to house the apparatus. This is particularly true with plants for extremely high voltages, and many ingenious and effective schemes have therefore been evolved for reducing the number of high-tension breakers, switches, etc., to a minimum.

I-*e. Main connections.* The paper read by Mr. D. B. Rushmore before the annual convention of the Institute in Milwaukee, May, 1906, on the subject of " Electrical Connections for Power Stations," covered the subject so fully that the writer will not devote much space to it here.

The relative advantages of the single bus-bar system, double bus-bar system, the group system, and the ring system are matters for discussion; the particular system decided on is often a matter of local conditions and a compromise between flexibility and cost.

Except where local conditions of low head or some other cause limit the size of the generators, it is usually advisable to have the transformer banks equal to the capacity of one or two generators, and to have the transmission lines of the same capacity as the transformer banks, to permit independent operation of the outgoing feeders with the minimum amount of apparatus and the maximum amount of flexibility. To obtain this flexibility and ready interchange of units, it is necessary in most instances to install a low-tension and a high-tension bus-bar, although occasionally it is feasible to have the generators connect directly to a bank of transformers or to have the transformer bank feed out directly on the line.

II. *Switchboards.* In practically all high-voltage plants of recent design the high-tension circuits are controlled by electrically operated oil-switches or circuit-breakers. The devices for use with these oil-switches are usually mounted on a switchboard of the (*a*) panel type, (*b*) pedestal type, or (*c*) desk, or bench-board type. Occasionally two or more of these types are used in the same station.

The material of the switchboard panels or the top of the control desk or face of pedestal is ordinarily blue Vermont marble or slate with either oil or marine finish. Blue Vermont marble, in the opinion of many people, presents a somewhat finer appearance than the slate, but it has the drawback of showing oil, stains and scratches, and it is hard to obtain a good match for large switchboards. The difficulty of keeping an exact record of the shade and markings of the marble shipped to a certain customer in case it is desired to supply additional panels or additional desk sections at a later date, militates somewhat against its use.

The slate, whether marine finish or oil finish, has the advantage of presenting a far more uniform shade and a shade which may be duplicated with almost absolute certainty when additions are desired. While it is almost impossible to remove a deep scratch or bad spots from a polished blue Vermont marble panel, it is a fairly simple matter with oil-finished or marine-finished slate. The oil-finished slate panel can be treated with vaseline, while with marine finish, additional paint put on with an atomizer can be used to cover any spots, scratches or other imperfections. The dull-black finish of the slate, moreover, causes the instruments, controlling devices, etc., to stand out in bolder relief and has no tendency to reflect the light in the eyes of the attendant.

II-*a*. *Panel boards.* Where the panel type of board is used, the panels are simply modifications of those required for lower voltages. The usual equipment of instruments for the generators transformers, feeders, etc., are mounted on the same panels as the controlling devices. This type of construction is used where the number of units is comparatively small, and the length of the board will not be too great. It is also employed where the space needed for the instruments is so great that any attempt to reduce the length of the operating board by mounting the controlling devices on a desk, or any more compact arrangement, will result in placing the instruments at such a distance from the operator that it will be difficult for him to see their scales and pick out the meters belonging to any one circuit. The plant of the Canadian Niagara Power Company is equipped with this type of panel board.

II-*b*. *Pedestal type*. This type of control is ordinarily used in plants with voltages lower than those referred to in this paper and where the number of generators is small in comparison with the number of feeders. In this case the generators are controlled from pedestals while the feeders are controlled from panels. This system is, however, sometimes used for high-voltage plants and was adopted for the distributing station of the Ontario Power Company at Niagara Falls. With these control pedestals it is customary to furnish posts for the instruments.

II-*c*. *Control desk or bench board*. Where it is desired to reduce the length of the operating board to a minimum, it is customary to install a control desk or bench board, and to mount on the top of the desk the various controllers for the circuit-breakers, electrically operated field-switches, field rheostats, governor motors, etc. Wherever possible, the instruments for the various circuits are mounted in such a position relative to the sections of the control desk as to indicate clearly to the station operator the instruments belonging to particular circuits.

With a control desk, the instruments may be mounted either on independent switchboard panels, on panels forming the back of the control desk, or in an instrument frame back of and usually higher than the top of the control desk, or on instrument posts. Where independent panels are used with a control desk, the panels usually occupy a greater amount of space than the desk, and it is possible for the station operator to become confused in determining the instruments belonging with a certain generator or feeder whose controlling devices are on the desk. As a rule, card-holders or name-plates are placed both on the desk and in the panels, and the grouping of the instruments is made to correspond as far as possible, with the grouping of the controlling devices.

Where the instrument panels form the back of the control desk the instruments are arranged to correspond in location with the controlling devices for the same circuits. This is the type of desk used by the Electrical Development Company at Niagara Falls.

A modification of this arrangement permits the station attendant to face the generator room and readily observe the operation of the machine he expects to control. An independent instrument frame is provided back of, and above the control desk and its height is such that the operator looks over the top of the desk and under the bottom of the frame.

A control desk 18 ft. long and an instrument frame of the type referred to are shown in Fig. 1, which illustrates the equipment being furnished for the control of six 5000 kw. generators, six banks of 88,000-volt transformers, and four 88,000-volt transmission lines.

In the plant for which the desk shown in Fig. 1 is used, each of the six transformer banks is provided on the high-tension side with an electrically operated oil circuit-breaker and a double set of disconnecting-switches, so that a bank of transformers may be connected to either of the two sets of high-tension bus-bars. These two sets of high-tension bus-bars are divided in the middle, but may be tied together through electrically operated junction circuit-breakers. The two sets of busbars on each side of the junction breakers may also be connected by means of electrically operated tie-breakers.

The four outgoing transmission lines are each provided with an electrically operated oil circuit-breaker and a double set of disconnecting-switches, so that the breaker may be connected to either of two sets of bus-bars. With this arrangement it is possible to operate the four transmission lines entirely independently, and a very flexible combination of generators, transformers, and lines may be obtained.

The top of this desk is made of marine-finished slate, while the ends, front, and back are made of planished steel plate, which is light, strong and readily removable to permit access to the interior of the desk. The instrument frame is of steel and the unit idea has been carried out to allow for future extensions.

This desk, like most of those where the connections are at all complicated, is provided with a miniature bus-bar system with the usual red and green lamps to indicate whether the breaker is open or closed. As the double-throw system on the high-tension circuits is obtained by means of disconnecting-switches, miniature disconnecting-switches are placed in the mimic bus-bars. The idea is that the station attendant, after closing or opening any of the high-tension disconnecting-switches, will report the fact to the switchboard operator so that the latter may set the miniature ones to correspond. As the arrangement of the disconnecting-switches is not likely to be changed from day to day, it is believed that this scheme will furnish the operator with

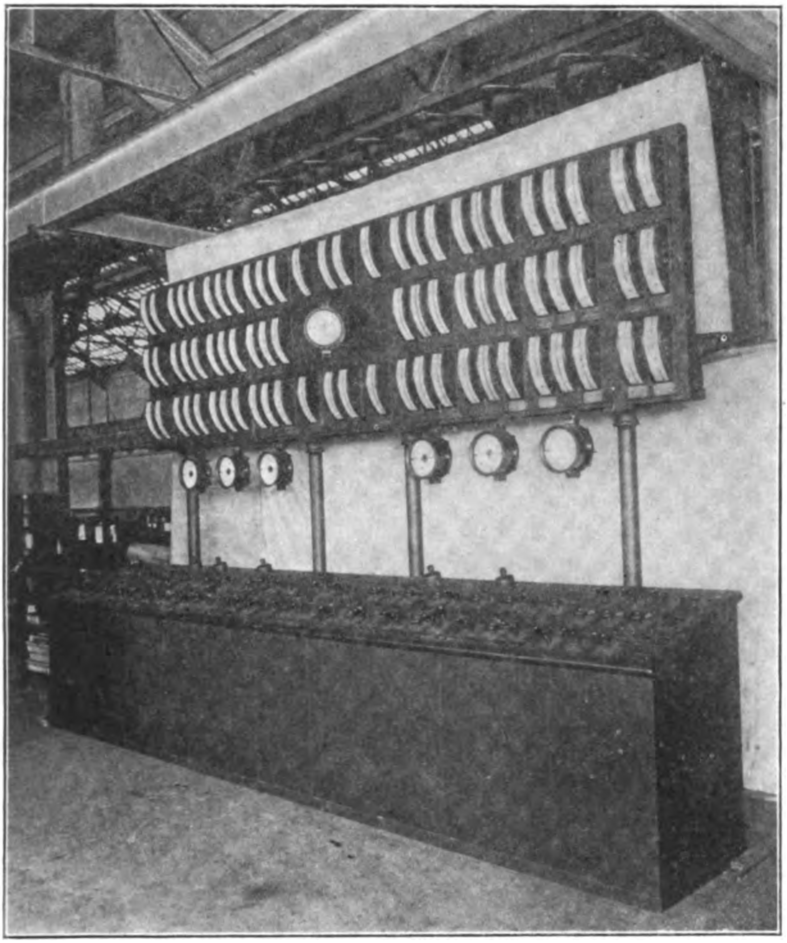


Fig. 1—Control desk for 88,000-volt plant

all necessary information as to the conditions of the high-tension connections.

In this plant the electrical control is extended to the field and exciter circuits as well as to the generators, transformers and lines. All the controllers, etc., are mounted on the top of the desk, the instruments being in the switchboard frame. With the exception of the power-factor meters, where a 360-degree scale was desired, and the synchroscope, where it is necessary for the needle to revolve, all the meters, both alternating current and direct current are of the same general appearance.

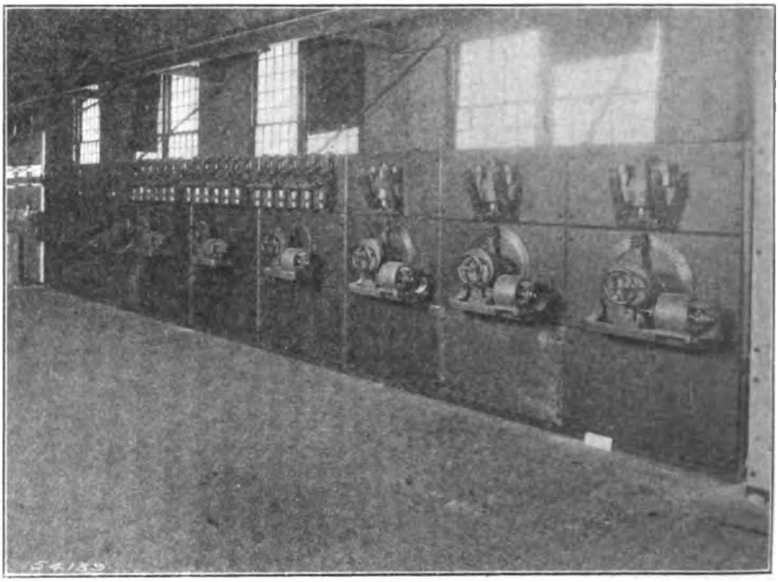


FIG. 2—Switchboard for exciter and field control for 88,000-volt plant

The motor-operated rheostats and the solenoid-operated switches for the exciters and the field circuits of the generators are arranged to form the panel board shown in Fig. 2.

The four outgoing 88,000-volt lines were each provided with a complete set of graphic recording ammeters, voltmeters, wattmeters, power-factor meters, and frequency meters, as well as polyphase integrating wattmeters.

The control desk for the line and transformer circuits in the receiving station of this plant is very similar to that for the generating station, but some additional refinements are being introduced. Instead of having miniature disconnecting-switches on the desk, small green telephone lamps will be placed in the miniature bus-bar system on the desk. These lamps will be connected in series with a standard incandescent lamp and a snap-switch located in the high-tension room, or in the passage way from which the disconnecting-switches are to be operated. The intention is to have the station attendant, after pulling out the disconnecting-switches, turn on the snap-switch and in this manner light the green lamp on the desk and the standard lamp near the switch. In a similar manner, after closing the disconnecting-switch, the snap-switch is turned to extinguish the light. Failure of the telephone lamps would indicate the danger position; that is, that disconnecting switches were closed.

In this receiving station, as it will be difficult for the attendant in the passage-way near the disconnecting-switches to see whether the oil circuit-breaker is open or closed, red and green lamps will be installed opposite each set of disconnecting-switches. These lamps will be operated by a signal-switch on the oil circuit-breaker, in the same manner as the red and green indicating lamps on the control desk.

The synchronous motors of the motor-generating sets, as well as the gas-engine-driven generators for the reserve power, are to be operated from the control desk, while the railway generators, alternating-current and direct-current feeders will be controlled from panels.

II-*d. Oil-switches and circuit-breakers.* The terms "oil-switch" and "oil circuit-breaker" are used synonymously in this paper. While in a few cases the oil-switches for high-tension plants may be and are operated by hand, these cases are exceptional, and only the oil-switches or breakers intended for electrical operation will be considered. These are usually one of two distinct types, and the engineer has to weigh the relative advantages of the different designs.

One type of switch is essentially a bottom-connected motor-operated switch intended for mounting in a masonry structure with each pole in a separate fireproof compartment, and each contact in a separate pot with terminals at the bottom of the pot. The other type of breaker is essentially a top-connected solenoid-operated self-contained breaker with the two contacts forming one pole in the same tank. The different features of these two designs will be taken up in order.

Bottom-connected versus top-connected. With the bottom-connected breaker, particularly when made with a wooden pot, considerable difficulty is experienced in making an oil-tight joint where the contact passes through the bottom of the pot. The top-connected breaker does not have this difficulty to contend with. With the bottom-connected breaker, the operating mechanism is entirely separated from the leads, while with the top-connected breaker the operating-rod as well as the leads pass through the top of the tanks and are necessarily closer together than the operating-rod and the leads of the bottom-connected breaker, which are at opposite ends of the pots.

Motor operation versus solenoid operation. On one switch the operating mechanism, consisting of a motor with suitable rods, springs, clutches, etc., is located on a base above the pots and supported by the walls which form the fireproof compartment for the poles. This mechanism is ordinarily at such a height from the floor that it is necessary for the station attendant to stand on a ladder in order to oil the motor or adjust any of the mechanism.

With the solenoid-operated breaker, the solenoid toggles, etc., are located on or near the floor in such a position that the station attendants can readily inspect and adjust them while standing on the floor.

Type of oil tanks. The motor-operated bottom-connected breaker is arranged with the two pots forming one pole of the switch mounted in a common horizontal platform supported at the four corners by wooden legs. This type of switch requires a comparatively small amount of oil and has the advantage that the circuit is opened in two independent receptacles per phase. With this bottom-connected arrangement, however· the sediment of the oil tends to settle on the contacts.

The circuit between the terminals in the bottom of the two tanks forming one pole of the breaker is made through metal plunger-rods attached to a metal cross-piece external to the tanks. A motor-operated mechanism connecting through wooden rods to the metal cross-piece moves it and the plungers vertically upward to open the circuit. The exposed metal parts above the tank and the bare terminals below, necessitate the enclosing of the switch in a masonry structure for the protection of the attendant. Doors are provided for each compartment of the structure to permit the ready inspection of the tanks, etc., but the removal or breaking of a door leaves these live metal parts a source of danger.

This motor-operated bottom-connected switch is the type installed in the 60,000-volt circuits of the Electrical Development Company at Niagara Falls and Toronto.

With the top-connected solenoid-operated breaker, metal tanks with insulated linings are used, and the two stationary contacts forming each pole are located under the oil near the top of the tank where sediment cannot settle on them. These contacts are, however, carefully separated by barriers so that the same result is secured as though each contact were in a separate tank.

The circuit between these stationary contacts is completed by plungers connected to a cross-arm and moving vertically downward to open the circuit. These cross-arms are connected through wooden rods to a toggle mechanism operated by a single direct-pull solenoid located on the floor in front of the breakers. All the live metal parts are completely submerged in oil, while the leads brought out through the top of the case are very heavily insulated. As the tanks, mechanism, etc., are grounded for the protection of the attendant, there is no necessity of enclosing the breaker in a masonry compartment.

The tops of the tanks are so made that the terminals, contacts, etc., can be readily got at for inspection, etc. This top-connected breaker is built in two different types, one with boiler iron tanks for very large capacities and the other with sheet metal tanks for smaller capacities.

The solenoid-operated top-connected breaker with boiler-iron tanks is the type installed on the 60,000-volt circuits of the Ontario Power Company and is guaranteed to open safely under any condition of overload or short-circuit that might arise in a plant with 200,000 kw. capacity in generators. The general appearance and over-all dimensions of this 60,000-volt breaker are shown in Fig. 3 while Fig. 4 covers a similar breaker designed for corresponding service at 120,000 volts.

The other type of top-connected breaker, intended for smaller installations and provided with sheet-metal tanks with wooden lining, is shown in Figs. 5 and 6, the former giving the over-all dimensions and the general appearance of the 60,000-volt breaker, while the latter covers the corresponding 88,000-volt breaker.

While the advocates of the different types of breakers naturally favor their own design, and while either type of breaker can be arranged to work in with a scheme of enclosed or open wiring, the bottom-connected switch is essentially designed for in-

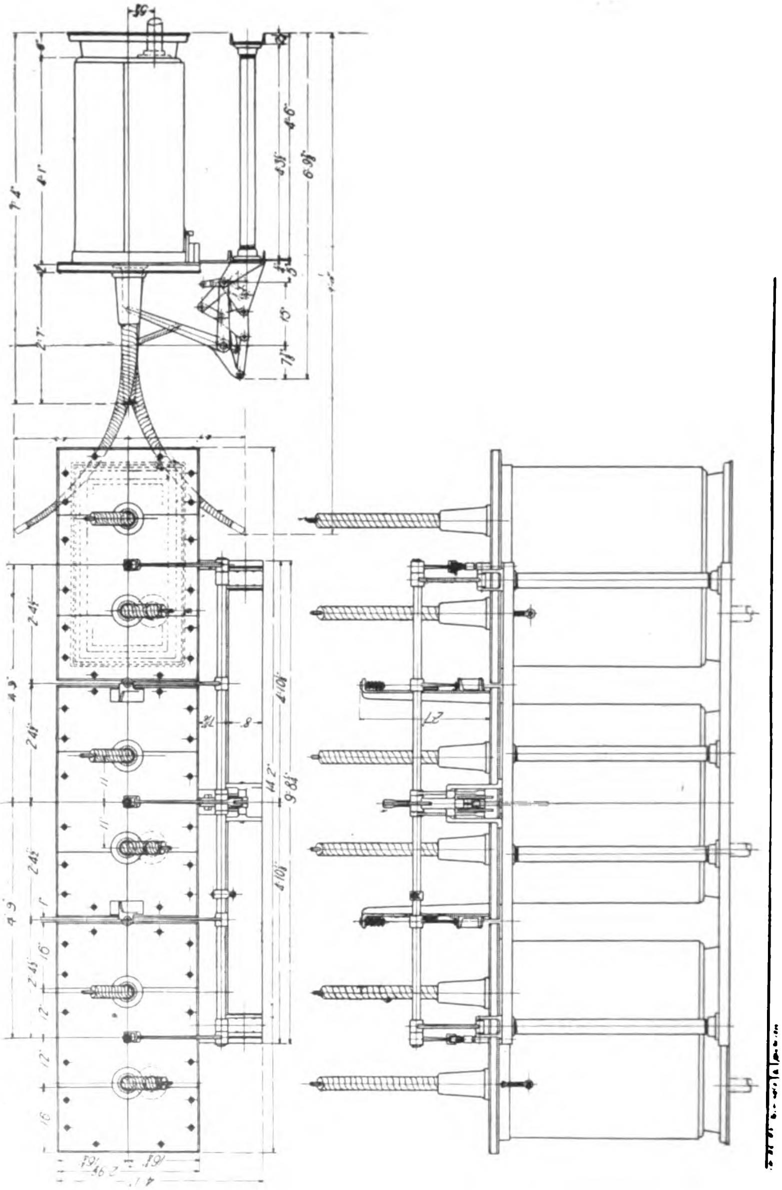


FIG. 3—60,000-volt, top-connected breaker with boiler-iron tanks

stallation where the wiring, bus-bars, etc., are placed in masonry compartments, while the top-connected breaker is intended primarily for plants where the high-tension wiring is overhead and entirely open.

The claim is made for each system that its type of breaker is less liable to get out of order than the other design. Both types are giving satisfaction under actual operating conditions, and the weak points of each breaker are being corrected as rapidly as they are discovered.

Where the control voltage is normal, the speed of operation is practically the same for the motor-operated and solenoid-operated breakers. If the operating voltage is too low, however, the motor-operated breaker closes and opens somewhat more quickly than the solenoid breaker, but with the motor-operated breaker some little time is required after the breaker closes until the motor has wound up the spring to trip the breaker out again.

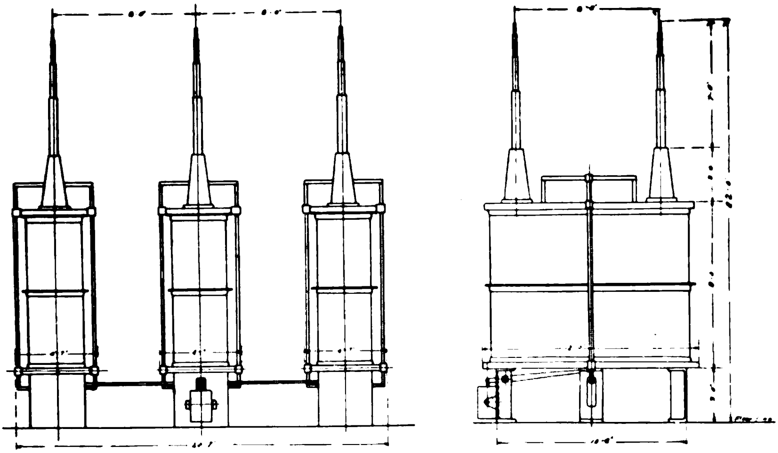


FIG. 4—120,000-volt, top connected breaker with boiler-iron tanks

Both designs of breakers may be so counterbalanced that in case of ordinary trouble either type will tend to fall open rather than to fall closed. However, if the wooden operating-rods to which the moving contacts are attached should break, the bottom-connected breaker will tend to fall closed, while the top-connected breaker will tend to fall open. Although there is little likelihood of breaking the wooden operating-rods of either type, such an accident is possible. Under this condition the top-connected breaker would have a decided advantage.

Where it is desired to have the breakers automatic, this is done by providing either a series trip-coil, ordinarily located in the tank underneath the oil, or a series transformer. In either case the operation of the series trip or the series transformer closes the direct-current trip-circuit, instead of operating directly on the mechanism of the switch or breaker.

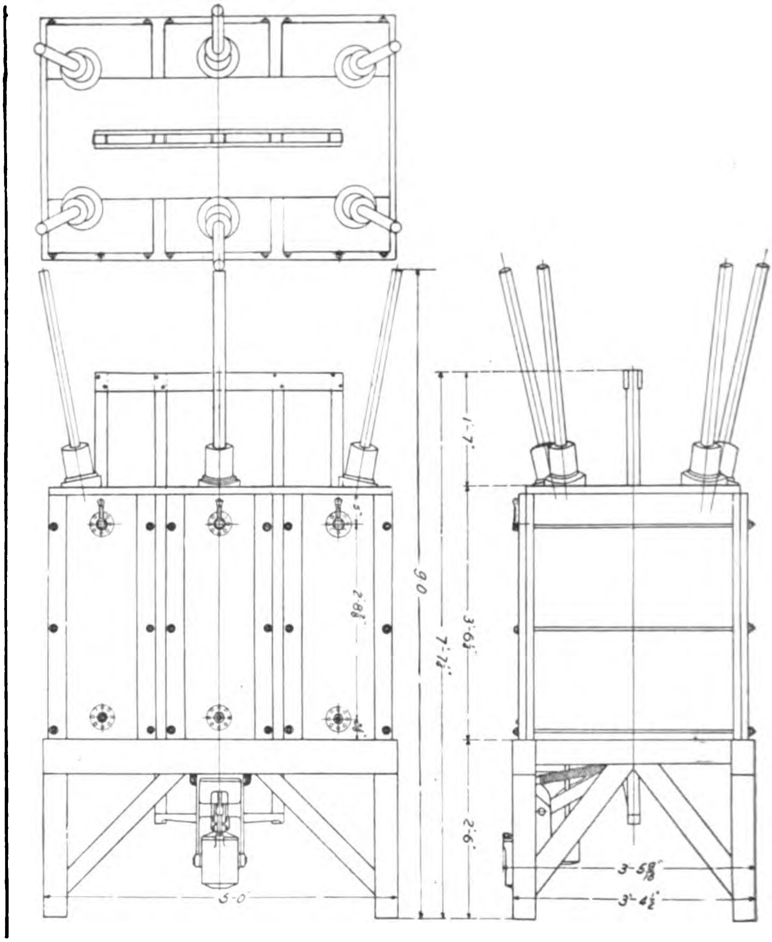


Fig 5—60,000-volt, top-connected breaker with sheet-metal tanks

The advantage of the series trip-coil is largely on account of its being cheaper, while the advantage of the series transformer arrangement lies in the increased insulation obtained and in the fact

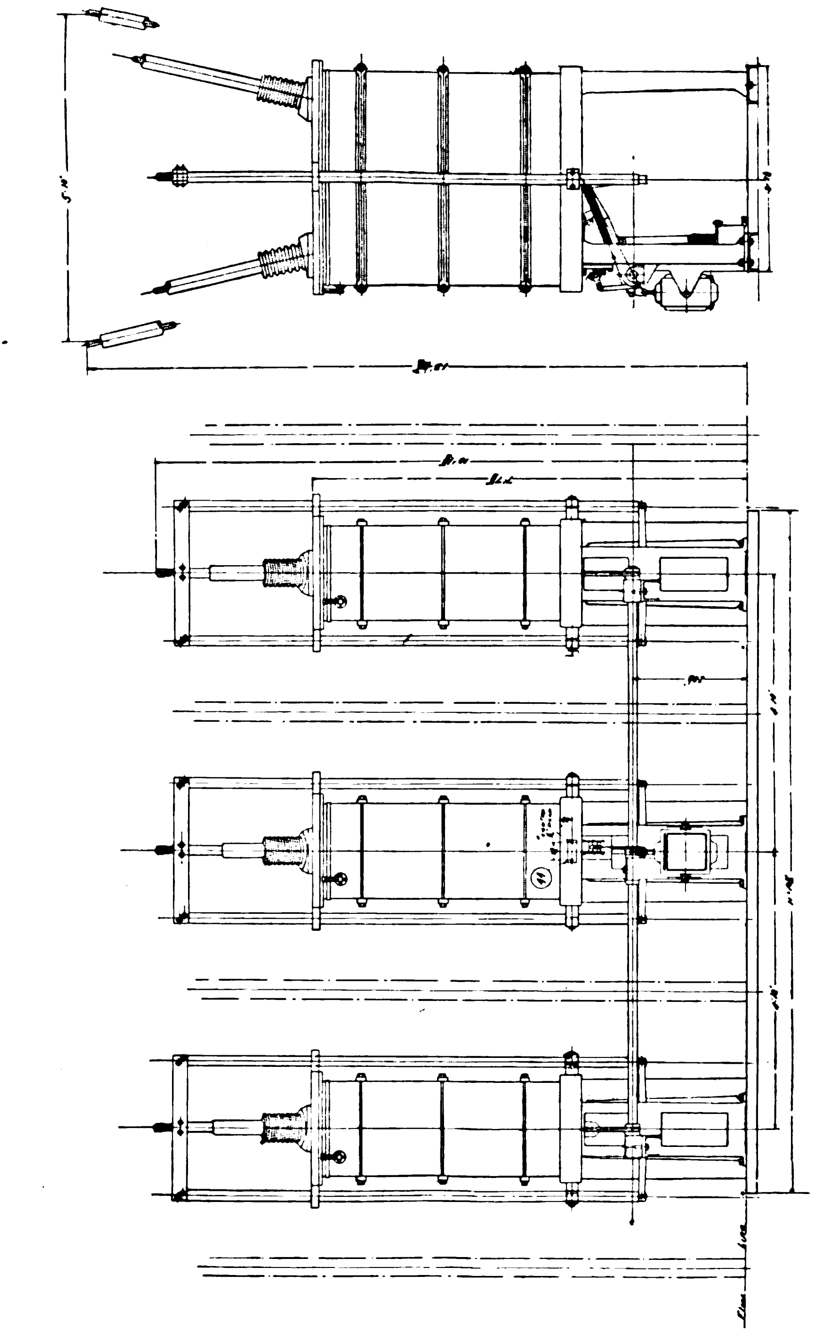


FIG. 6—88,000-volt, top-connected breaker with sheet-metal tanks

that series transformers may be needed in case it is desired to operate meters on the switchboard to indicate the current, output, etc., of the lines in which these high-tension breakers are connected.

The two types of breakers previously described may be arranged for operation either with series trip-coils or with series transformers.

While the question of automatic or non-automatic breakers for generators, transformers, and line circuits is often a matter of opinion, the general practice seems to be as follows. Generator circuit-breakers are usually made non-automatic, although occasionally provided with reverse-current relays. The oil circuit-breakers on the low-tension side of the raising transformers are usually provided with overload relays. The oil circuit-breakers on the high-tension side of the raising transformers are usually made non-automatic, although occasionally a differential relay is furnished which operates in case of a local short-circuit in the transformer to cut off both the high-tension and the low-tension breakers.

The breakers for the outgoing transmission lines are ordinarily provided with overload relays. Relays for the different breakers are made instantaneous, definite time relays, or inverse time relays, depending on conditions.

II-*e*. *Disconnecting-switches*. The disconnecting-switches used on high-tension plants consist almost invariably of a plain knife-switch mounted on high-tension line insulators, this switch being operated by means of a pole with a hook in one end. In some plants an operating mechanism is installed for opening the three disconnecting-switches of a three-phase circuit at the same time.

Where the disconnecting-switches are not readily accessible from the operating floor, they are sometimes provided with a projecting arm so that the station attendant may more readily open them by means of a direct vertical pull or push of his operating stick. In some cases where the disconnecting-switches are located in inaccessible positions, it has been proposed to open and close them by means of a solenoid or motor-driven mechanism. These high-tension disconnecting-switches have in most cases been mounted on porcelain insulators, but composition insulators have also been used for this purpose.

The pins for these insulators are made of wood, metal, or composition, depending largely on the individual preference of the designer. The relative advantages of the different kinds of insulators and pins is not a question which comes within the scope of this paper.

II-*f*. *Protective apparatus.* In connection with lightning protection for high-tension plants, choke-coils, either of the open type or of the oil-immersed type, have been largely used. In this work the strain developed across adjacent turns in the choke-coils is so great when the coil performs the function normally expected of it that oil insulation is necessary to obtain the best results.

II-*g*. *Bus-bars and wiring.* As mentioned in the earlier portion of this paper, the bottom-connected breakers are chiefly used with the enclosed system of wiring, and bus-bars and the top-connected breaker with the open system. There is a considerable difference in opinion between the advocates of the enclosed and open systems regarding the relative advantages and disadvantages of the two arrangements.

The enclosed system of bus-bars, wiring etc., for high-voltage plants is an extension of what is acknowledged to be the best standard practice for voltages up to 13,000, and is intended to provide additional safety for the station operator and additional security against a shut-down such as might be caused by something getting across the bus-bars.

II-*h*. Those who favor the open system base their arguments on the following grounds. First, the violence of an arc and the destructive effect of short-circuit depend on the amount of current available at the point of short-circuit, or, for the same amount of power, is inversely proportional to the voltage, so that while fireproof barriers and cellular construction are required on large capacity plants of comparatively low voltage, they are unnecessary for higher voltage plants of the same, or even larger capacity.

Secondly, as the fireproof barriers offer a more or less perfect ground for high-voltage circuits, the striking distance from wire to ground has to be greatly reduced over what could be obtained with open wiring in the same space. The higher the voltage the more perfect the ground.

Thirdly, the use of enclosed bus-bars and wiring ordinarily necessitates several floors or galleries and a more expensive building than is the case with the open wiring.

Fourthly, it is more difficult to inspect and repair bus-bars, wiring, disconnecting-switches, lightning-arresters, etc., that are boxed in masonry compartments and only visible and accessible by the removal of doors than if everything is in plain sight. Incipient trouble will be noticed far sooner with open wiring than with enclosed, and inspection will be more frequent and thorough if the station attendant in a few minutes' walk can see everything, than if he had to remove several hundred doors and visit two or three floors to examine the condition of the apparatus.

Typical examples of the enclosed and open systems of wiring for 60,000-volt circuits are the transformer houses of the Electrical Development Company at Niagara and Toronto, and of the Ontario Power Company at Niagara Falls.

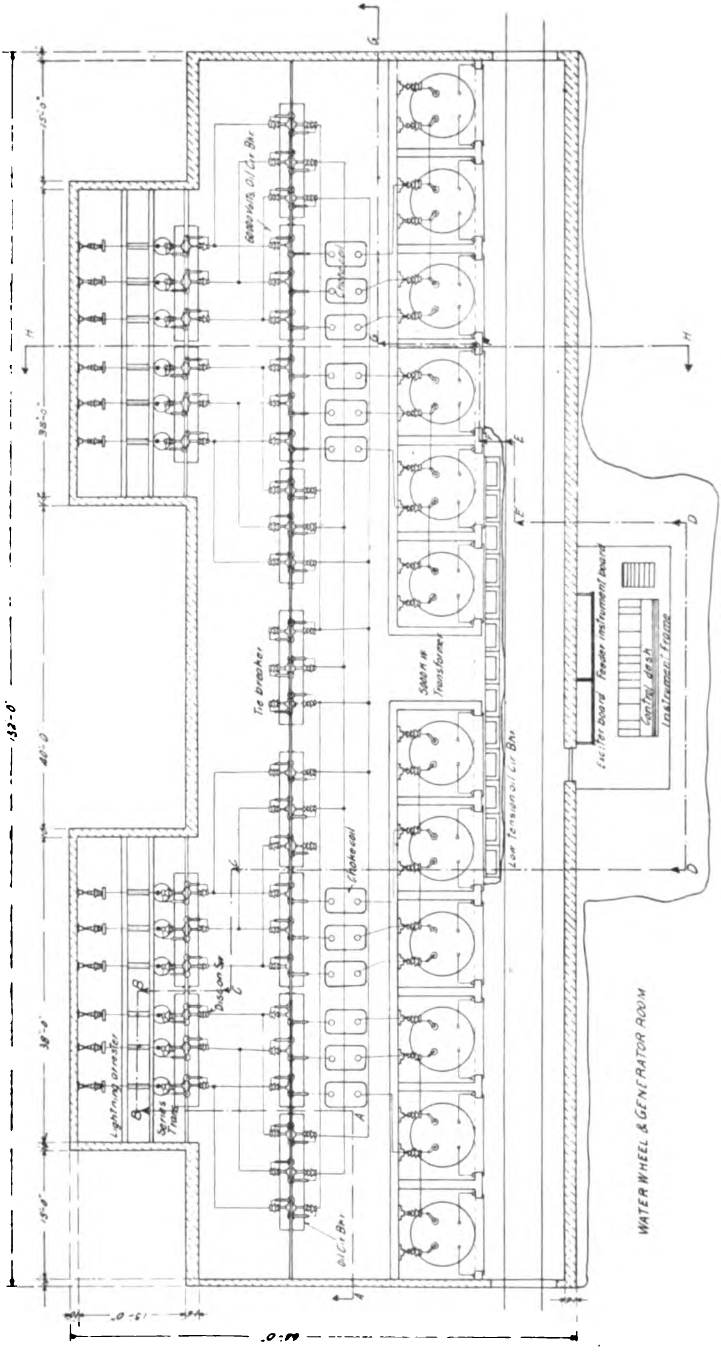
One of the most striking differences in the two plants, due partly to the use of bottom-connected breakers and enclosed bus-bars in one case, and the top-connected breakers and open bus-bars in the other, is in the location of the disconnecting-switches which isolate the oil-switches or circuit-breakers from the bus-bars.

In the former case they are below the oil-switches and invisible.from the switch-room without removing the doors of the switch-compartments and cannot readily be opened without going down stairs. The station attendant adjusting or cleaning a breaker is on a different floor from the disconnecting-switch, which, if closed through a misunderstanding of orders by a second attendant, will make the oil-switch terminals alive, with consequent grave danger to the cleaner.

In the station of the Ontario Power Company the disconnecting switches are directly above the oil circuit-breaker, can be pulled by the attendant standing at the breaker, and cannot readily be closed without the knowledge and consent of the man working on the breaker.

III-*a*. *Present stations* 60,000 *volts*. In order to give an idea of the relative space required for 60,000-volt and 100,-000-volt plants, the preliminary drawings prepared for two different stations of approximately the same capacity and same general arrangement are shown in Figs. 7, 8, 9, 10, 11, and 12.

Figs. 7, 8, and 9 show the plan, elevation, and section of the transformer and switching house to be built on the side of a hill for a plant containing eight 7500-kw. 6600-volt generators, and twelve 5000-kw. 6600- to 60,000-volt step-up transformers, with four outgoing transmission lines. In this station the transformers are delta-connected on both the low-tension and high-tension sides and knife-type disconnecting-switches have



[FIG. 7—Plan of transformer and switching house, 60,000-volt plant been provided for cutting out any one transformer in any bank. The high-tension connections are so made that each transformer bank feeds a short section of bus-bars. This short section of bus-bars can be connected through a circuit-breaker to the main high-tension bus-bar, or through a different circuit-breaker to the outgoing transmission line.

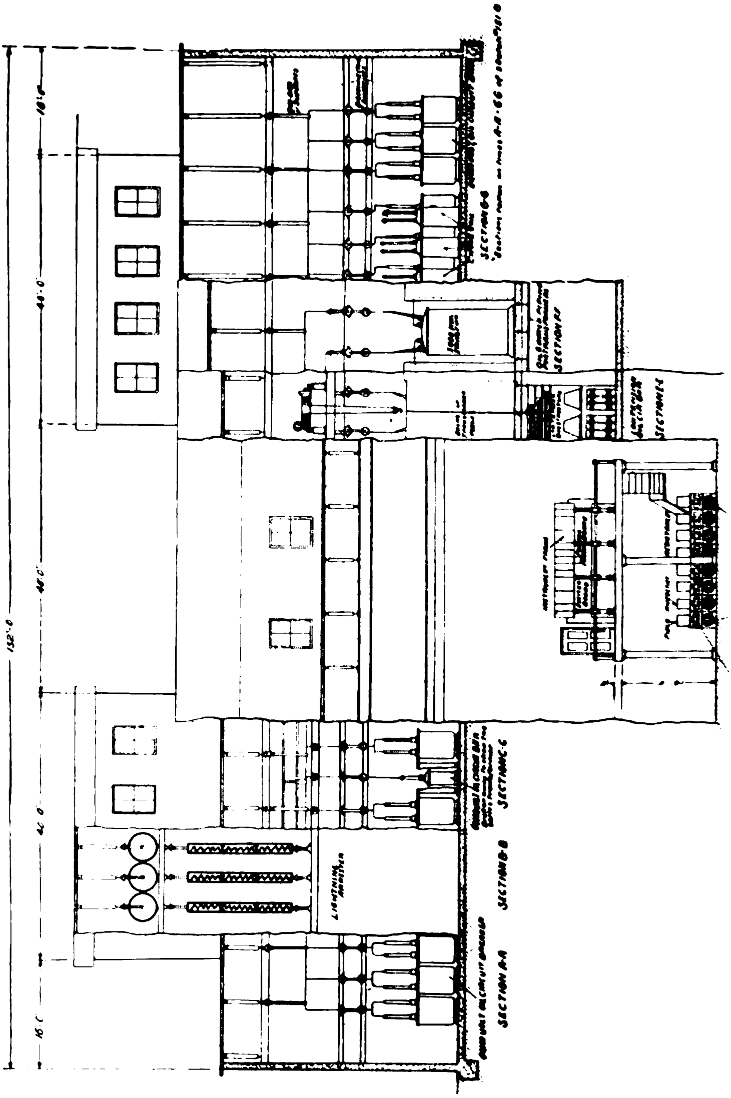


FIG. 8 - Elevation of transformer and switching house, 80,000 volt plant

III-*b*. *Present stations* 100,000 *volts.* Figs. 10 and 11 show respectively the plan and section of the transformer and switching house, also on the side of a hill, proposed for the control of ten 5000-kw. 6600-volt three-phase generators, and twelve 4000-kw. 6600- to 66,000-volt step-up transformers. This station will be first installed with the transformers connected in delta both on the low-tension and on the high-tension, and will later be changed over to star connections on the high-tension for operating at 100,000 volts. All the bus-bars, wiring, etc., have been spaced suitably, and all breakers, switches, etc., supplied for this higher voltage.

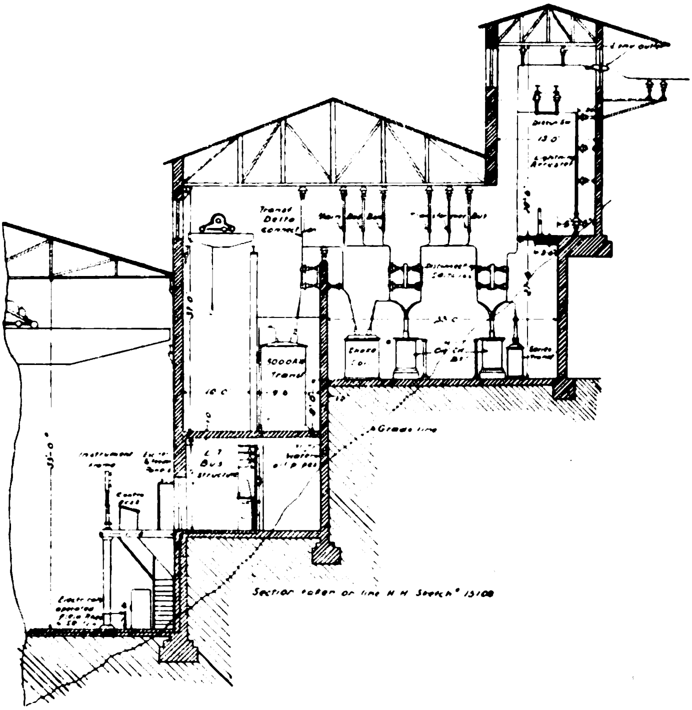


FIG. 9—Section of transformer and switching house, 60,000-volt plant

While operating at 66,000 volts, disconnecting-switches will be used both on the low-tension and on the high-tension side of the step-up transformers for cutting any one transformer out of the bank.

The main connections of this plant will be similar to those of the plant previously described; namely, each bank of trans-

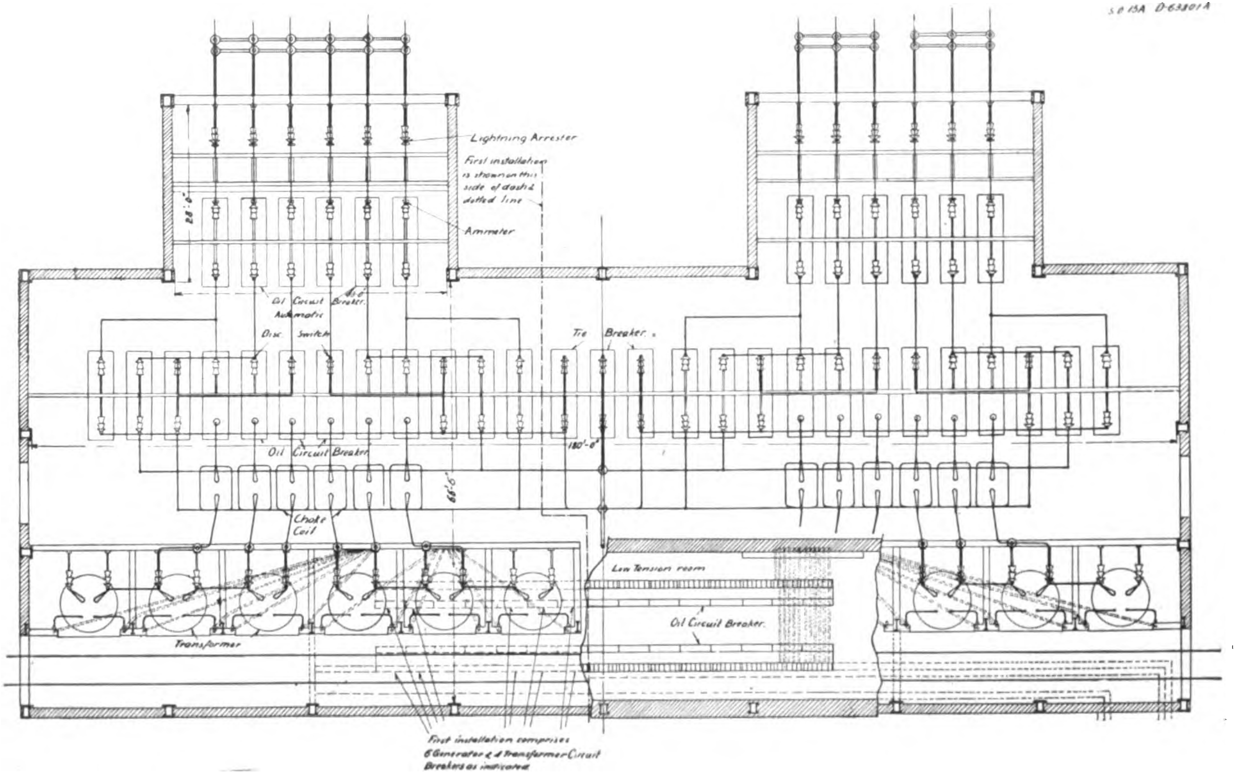

S 0 15A D-63801A
Lightning Arrester
First installation is shown on this side of dash & dotted line
Ammeter
28'-0"
Oil Circuit Automatic Breaker
Disc. Switch
Tie Breaker
Oil Circuit Breaker
180'-0"
66'-6"
Choke Coil
Low Tension room
Oil Circuit Breaker
Transformer
First installation comprises 6 Generator & 4 Transformer Circuit Breakers as indicated

FIG. 10—Plan of transformer and switching house, 100,000-volt plant

formers feeds a short section of transformer bus-bar, which transformer bus-bar can be connected through a breaker either to the main station bus-bar or through another breaker to the high-tension outgoing feeder.

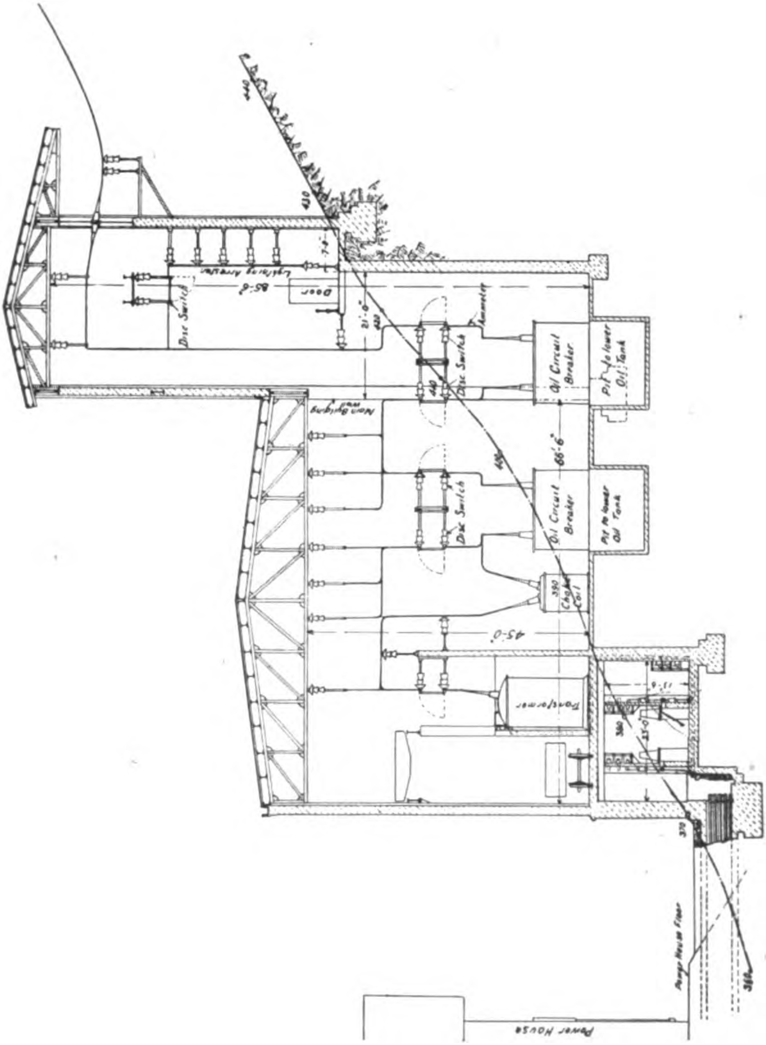


FIG. 11—Section of transformer and switching house, 100,000-volt plant

The low-tension connections are arranged on a straight double-throw system, as indicated by the miniature bus-bar on the control desk shown in Fig. 12, and it may be noted that the entire equipment of this station will not be installed at first.

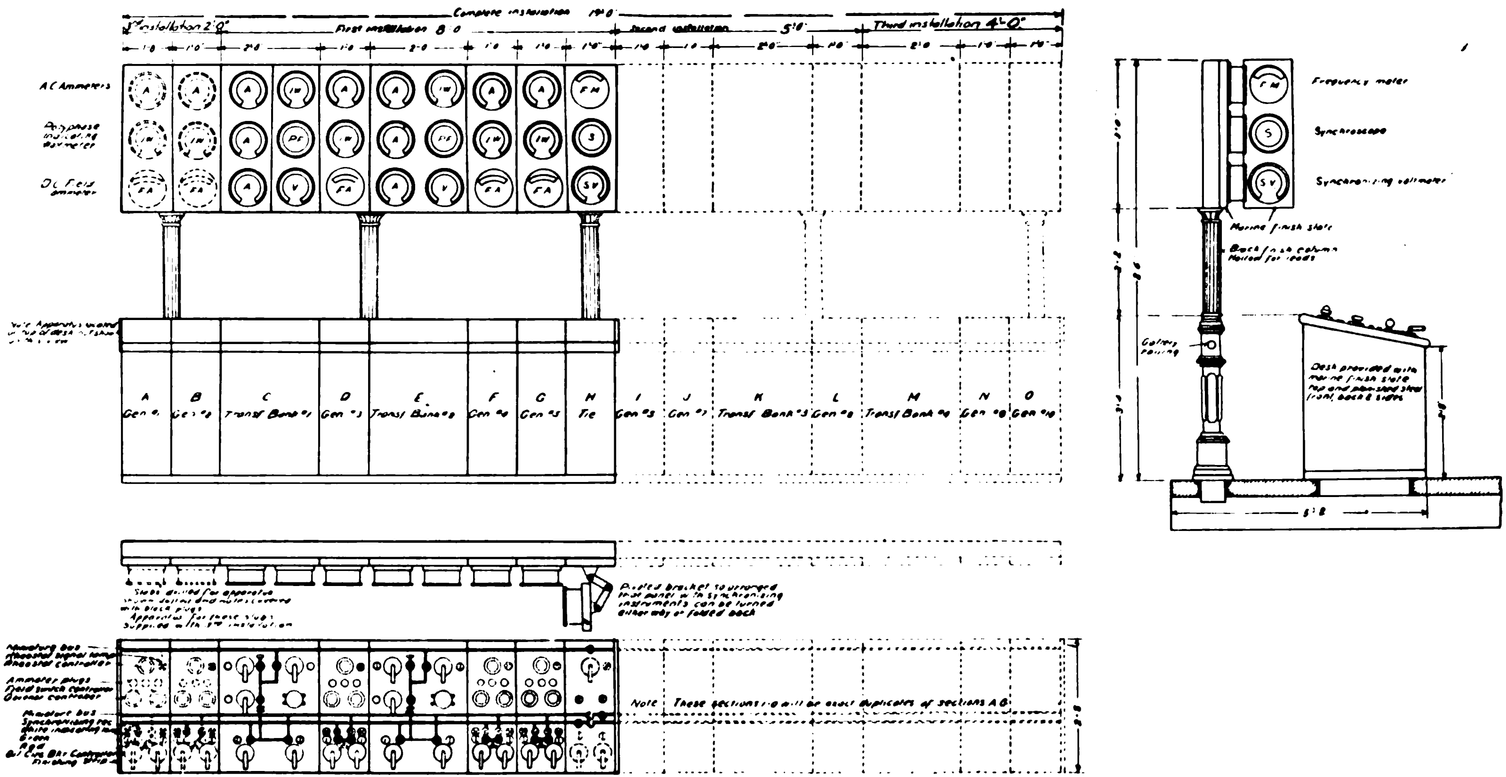


Fig. 12—Control desk for 100,000-volt plant

IV-*a*. *Future stations*; *indoor*. As may be noted from Figs. 6 to 11 the amount of space necessary for the circuit-breakers, switches, bus-bars etc., for a high-voltage transmission plant is comparatively great and it requires a large building to contain them.

IV-*b*. *Future stations*; *outdoor*. It is quite possible that in the not far-distant future where the climate is not too severe, high-tension transformer houses with their breakers, bus-bars, etc., will no longer be used; the transformers, oil circuit-breakers, disconnecting-switches, bus-bars, wiring, and connections will probably be in the open air.

The oil-immersed water-cooled transformers and the electrically-operated oil-switches are well designed to stand out-of-door conditions. Disconnecting-switches have often been used in high-tension transmission lines mounted on the poles, and the use of electrolytic lightning-arresters with the choke-coils combined in the transformer cases will readily permit of this out-of-door operation.

The top-connected circuit-breakers and the open arrangement of bus-bars and wiring are particularly suited for an out-of-door transforming station, and it may not be long before such a station is designed and installed.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

REPORT OF LIBRARY COMMITTEE

In accordance with the provisions of the Constitution, we present the following report of the more important features of history of the Library of the Institute for the year ending April 30, 1907; the present condition of the several funds from which the support of the Library is directly derived; its present status as one of the associated libraries in the new Engineering Societies Building; and plans for the future.

RECENT SLOW GROWTH.

During the past four years the overshadowing activity in securing by subscription the fund to purchase the land for the new building, and the labor attending its construction and equipment have naturally and properly occupied the minds and time of the active members of the Institute to an extent which has prevented such rapid progress of the Library as was recorded in the report of May 1, 1903.

It should, however, be noted that even under these unusual circumstances and amid these extraordinary calls upon the interest and resources of the members and friends of the Institute, the Library has in the past four years increased in number of volumes (not including duplicates) from 7727 to 10577, a gain of 2850 volumes; and in valuation of volumes from $16211.10 to $21726.47, a gain of $5515.37. This increase of over 35 per cent. in number of volumes is gratifying as indicating what may hereafter be accomplished now that the Library has a permanent fireproof home, offers greatly increased conveniences, and is in other ways richly deserving of the cordial support of a rapidly growing number of members and friends of the Institute.

GIFTS OF BOOKS.

During the past year Mr. Edward D. Adams has once more illustrated the practical value of his support of the Institute Library by contributing a collection of about 200 scientific books, a list of which appeared in the October issue of the PROCEEDINGS.

Similarly, the McGraw Publishing Company has donated about 25 of its recent publications, which supply in part the serious need of the latest editions of electrical text-books, and new publications of the same character. The same Company has also turned over to the Institute a large collection of unbound electrical patents issued in this country during the past 15 or 20 years.

Another and very complete collection of United States electrical patents issued from the early years down to about 1904 has just been donated by Messrs. Dyer and Dyer. This will prove specially important in the equipment of the headquarters of some progressive Institute Branch.

The complete list of donors for the year is as follows:

ADAMS, E. D.
ALLEGEMEINE ELEKTRICITATS GESELLSCHAFT
ALLEN, W. F.
AMERICAN RAILWAY ASSOCIATION
CANFIELD, DR. JAMES W.
CARROLL, WM.
CARTY, J. J.
M. LE DIRECTEUR CONSERVATEUR NATUREL DES ARTS AND METIERS
CROCKER, F. B.
DUNBAR, JAMES W.
DYER AND DYER
L'ECLAIRAGE ELECTRIQUE
GERARD, LEON
GAUTHIER, VILARS
HAMACEK, ADOLPH F.
HAMMOND, ROBERT
INSTITUTION OF ELECTRICAL ENGINEERS
JENKS, W. J.
LIBRARY OF CONGRESS
MCGRAW PUBLISHING CO.
MARTIN, T. C.
MASS. BOARD OF GAS AND ELECTRIC LIGHT COMMISSIONERS.
MULOCK, SIR WM.
NEW YORK CITY COMMISSION ON ELECTRIC LIGHT
PEDERSON, F. M.
PLASS, J.
RIES, E. E.
ROBERTSON, LESLIE S.
ROSENTHAL, S. W.
SHELDON, DR. SAMUEL
SHEPARDSON, PROF. GEO. D.
SOCIETY OF ARTS
SWENSON, BERNARD V.
TALBOTT, FRANK
TALTAVALL, T. R.
VAIL, J. H.
WARD, GEO. G.
WEAVER, WM. D.
WHEELER, SCHUYLER S

STATISTICS OF LIBRARY, MAY 1. 1907.

Source	Titles.	Volumes	Pamphlets	Valuation
Report of May 1, 1906	7400	10717	515	$22.069.31
PURCHASES:				
Carnegie Fund				
Donation Fund	7	18		22.45
Mailloux Fund	4	6		23.20
Institute Appropriation	3	6		26.00
Periodicals	25	58		116.00
GIFTS:				
Edward D. Admas	162	300		168.00
McGraw Publishing Co	23	23		41.25
Miscellaneous	25	58	50	85.00
Gross Totals, May 1, 1907	7649	11186	565	$22,551.21
Duplicates	308	609		824.74
Net Totals, May 1, 1907	7341	10577	565	$21,726.47

In the following table of total valuation of the Library, May 1, 1907, the furniture and cases are those brought from the old offices at 95 Liberty street, no account being included of the new furniture, stacks, etc., provided as a part of the initial equipment of the Engineering Societies Building:

Total Valuation.

Books	$22,551.21
Stacks	1,470.25
Furniture, Catalogues, Cases, etc	208.28
	$24,229.74

The following tabulations give the state of the four funds from which the Library Committee is entitled to draw:

Donations (General Library Fund).

Dr.		Cr.	
Balance May 1, 1906	$232.56	Purchase of books	$ 2.64
Interest May 1, 1907	7.08	Unexpended	237.00
	$239.64		$239.64

Carnegie Fund.

Dr.		Cr.	
Balance May 1, 1906	$3952.37	Wheeler Bibliography	$ 541.85
Interest May 1, 1907	119.08	Unexpended	3529.60
	$4071.45		$4071.45

Mailloux Endowment Fund. ($1,000).

(Proceeds for the maintenance of certain sets of periodical publications.)

Dr.		Cr.	
Balance May 1, 1906	$ .75	Subscription	$23.20
Interest May 1, 1907	30.00	Unexpended	7.55
	$30.75		$30.75

International Elec. Congress of St. Louis, 1904, Fund. ($2,140.10.)

(Proceeds for the purchase of international electrical literature.)

Dr.		Cr.	
May 1, 1907		Unexpended	

In conformity with Section 33 of the By-laws, this Committee submitted to the Board of Directors at its meeting of October last an estimate of requirements for the year commencing Nov. 1, 1906. The appropriation which resulted is stated below. Pursuant to Section 37, the expenses for the year commencing May, 1 1906 are stated on the other side of the account. This is in accordance with the method pursued in prior reports of this Committee although the actual unexpended balance of the present appropriation year, remaining after six months of operation to the credit of this Committee, with which to meet bills not yet received and the expenses of the coming six months beginning May 1, 1907, is $1582.14 instead of the amount represented by the apparently unexpended balance for the year ending April 30, found in the appended statement.

The charge for rent is calculated for the past year at the rate paid by the Library at the former quarters, from which removal took place about Feb. 1, 1907.

Institute Appropriation Account.

Dr.		Cr.	
Appropriation for Maintenance for year ending October 31, 1907	$3363.00	Rent	$1475.04
		Insurance	106.35
		Salary, Librarian	713.20
		" Assistant	174.00
		Building	135.05
		Supplies	7.95
		Subscriptions	26.00
		Express and Postage	8.80
		Books	27.73
		Fixtures	73.08
		Miscellaneous	117.05
		Unexpended	498.75

The Most Urgent Need

is that of modern text-books to meet the everyday necessities of the patrons of the Library. Only a moderate percentage of the standard works of the past twenty-five years are now on our shelves. A notable opportunity is now presented to some member or friend of the Institute, or several acting together, to contribute a relatively moderate amount for this special object, which has never before assumed anything like its present importance; particularly in view of the fact that the use of this Library is now offered to the public and to nearly 10,000 members of the two founder societies, which have now become associates of the Institute in the new headquarters, as will be explained more in detail at the end of this report.

Bibliography of the Wheeler Gift

The work of digesting the entire Wheeler Gift and preparing the Bibliography for the printer, which has for five years been progressing in the hands of Brother Potamian, is still going forward under the management of W. D. Weaver, who was appointed this year a special committee to complete the task to which he has given so much time and thought since Past-president Wheeler presented the collection to the Institute. Thus the loss which was felt in Mr. Weaver's resignation of leadership in Library affairs, after so many years of most painstaking labor, often at great personal inconvenience and always marked with characteristic grasp of detail and assumption of the entire load of committee responsibility, has been mitigated by his willingness to retain the direction of this important publication, for which funds were provided by Mr. Carnegie. Instead of being restricted to the 1400 members who formed the Institute in 1901, this octavo volume of probably 500 pages, affording annotations to all of the more important books and pamphlets in the collection, will be offered, during the coming fiscal year, to about 4500 members who make up the Institute of to-day; while many Libraries, scientists and engineers outside the Institute will doubtless secure copies at some reasonable price.

Historical Museum

This is a new development naturally closely affiliated with the Library and merging into it by insensible degrees.

The first effective effort in this direction was made by Past-president

Wheeler shortly before his retirement from office last year, by enlisting the sympathetic coöperation of Mr. Edward D. Adams and then securing the adoption by the Board of Directors, of a general resolution, followed in January by a more specific authorization, best expressed in the language of the resolutions then adopted:

> "Resolved, That the Library Committee is hereby authorized to accept on behalf of the Institute, donations of original apparatus, models, photographs, manuscripts printed documents and similar exhibits, suitable for a museum of historical electrical material; also to accept the loan of material of the same general character which cannot be secured by gift.
>
> "Resolved, That each donation or loan accepted under the foregoing resolution shall be acknowledged by the Chairman of the Library Committee, specifying the articles received in sufficient detail to ensure subsequent identification, and reciting the conditions of gift or loan and acceptance."

The Board also appropriated $200 for the purchase of such cases, frames, etc., as might be desirable for making a start in this direction. The first donation, by Mr. Adams, was an elaborate and costly model, some four feet in length, of the high-speed, three-phase electric railway motor car which was operated on the Berlin-Zossen Railway, in 1903, at a speed of more than 150 kilometres per hour. Offers of early lamps, dynamos, regulators, etc., have been made by Messrs. James J. Wood of Fort Wayne, W. S. Andrews of Schenectady, A. J. Wurts of Pittsburg, Rudolph M. Hunter of Philadelphia, and a few others.

The Committee now invites correspondence regarding original relics, of the general character specified by the resolutions, which can be identified as genuine, and having a well-authenticated history; in other words, " first things " in electrical apparatus, pictures and manuscripts. It is not desired to secure models or papers simply because they are old. To adopt such a course would evidently result principally in establishing an electrical junk-shop. The purpose is to place the Museum at the outset on a high plane of excellence, by judicious selection of available material even though the collection grow slowly; by the exercise of special diligence in gathering and displaying information as to the detail of history which each exhibit represents; and by the provision of adequate protection during many years to come for each accepted article. Thus the conditions of security, permanency, and accessibility which invite contributions to the Library will equally encourage similar donations to the Museum.

Each article or group accepted will bear the name of the donor, and a careful registry will be kept of the conditions, if any, under which it has been contributed; to the end that the wishes of the donor regarding it may be kept in mind and respected by the Institute, in general accordance with the methods pursued in the case of articles donated to other corporate bodies, such as the Metropolitan Museum of Art.

Sub-committees

The unusual number and importance of the tasks devolving upon this Committee this past year has been lightened by a division of labor indicated by the duties of four sub-committees, as follows:

(1) Purchase of furniture and floor covering for Institute offices; Edward Caldwell, Frank N. Waterman.

(2) Library subscriptions, purchases and donations: Edward Caldwell, C. A. Terry.

(3) Increased Library utility: Professor Charles F. Chandler, C. A. Terry.

(4) Historical Museum: F. N. Waterman, W. J. Jenks.

Much consideration has been and will be given to devising and putting into practice plans for enabling members at a distance who cannot consult this Library in person, to secure many benefits from a liberal equipment and maintenance. It is proposed to offer facilities for getting certified excerpts from rare volumes, photographs of pages and diagrams, or translations from several foreign languages, all at a moderate charge; also to loan duplicate volumes under suitable restrictions. Correspondence is especially invited on this question of "increased Library utility."

REMOVAL TO PERMANENT QUARTERS

The completion and opening about January 1 of the new Engineering Societies Building, with its two spacious and convenient floors devoted respectively to reading room and stack room accommodations for the assembled libraries of the three founder societies, invited speedy removal from the extremely contracted and inadequate quarters at 95 Liberty street. This was accomplished in February without the loss or injury of a single volume belonging to the Institute Library. The transfer of the stacks to their permanent location necessitated entire rearrangement and a different system of mechanical support. Thus this transfer required much more time than the mere moving of the books, but everything was completed and the books carefully arranged early in April, and our section of the comfortable and well-lighted stack-room has been made fully available.

THE ASSOCIATED LIBRARIES

Thus far this report has dealt with the Electrical Engineers' Library as an institution by itself. There remain to be considered its relations to its newly associated libraries, and changes in administration which are required in consequence.

The formal dedication of the building, April 16 and 17, found the three libraries of the founder societies occupying their permanent home in coöperative arrangement, offering to the student an aggregate of about 35,000 volumes at the outset, each section in charge of its own librarian, but open primarily to any one of the 15,000 members of all the separate societies, and incidentally to engineering readers generally, outside the fraternity.

The books of the Institute now occupy exclusively two sections or alcoves of the reading room, and also, jointly with the other societies, two other alcoves; thus displaying on the thirteenth floor about one-third of its volumes. The main body of the ancient treasures of the Wheeler Gift, Latimer-Clark Collection, is suitably and securely housed in glass-front wire-protected cases in the stack-room, a few of the most precious books being displayed to the visitor in locked show-cases, with explanatory cards across the open pages. It is the purpose of the Committee to increase the number of these valuable volumes thus shown, as soon as permanent show-cases can be made.

By authorization of the Board of Directors of each of the three founder societies, the chairmen of their respective Library Committees are empowered to meet in conference and jointly direct the mutual relations which now exist. Messrs. Raymond of the Mining Engineers, Suplee of the Mechanical Engineers and the Chairman of this Committee have thus conferred and agreed upon several tentative conditions of coöperative action and rules of administration. Of these the following are of general interest:

"That no questions shall be decided by majority votes of the three representatives of the three societies, but that all decisions must be unanimous in order to become effective; dissent on the part of any one representative being sufficient to require a reference to the respective library committees, and ultimately, if necessary, to the governing bodies of the respective societies, excepting as to matters regarding which the regular single representative is clothed with full powers.

"That for the present, all consideration of the question of a new organization for the administration of the three libraries, or of the appointment of any additional or general librarian, shall be postponed.

"That the present arrangement, under which the three present society librarians administer the three libraries, each under the supervision of her authorized society representative, and in mutual coöperation as to matters of common interest or necessity, be continued.

"That the Reading Room be open on all week-days, from 9 a.m. to 5 p.m. Only members of the three founder societies, and others duly introduced by the Secretary or other authorized officer of one of the societies, will be permitted access to the alcoves or other spaces inside the rail.

"That for the protection and convenience of members, the Secretary of each society, will, upon application, issue to any member of his society in good standing a personal, non-transferable card, entitling him to the use of the libraries in the alcoves of the Reading Room. This card must be signed by the person receiving it, and surrendered at the desk at the time of its presentation. At every visit he must identify himself by signing his name in the registry.

"That non-members may, in the two outer alcoves, receive and consult books for which they call at the desk: or they may, on similar application to one of the secretaries, secure special cards admitting them to the inner alcoves under similar restrictions.

"The librarians shall have no discretion in the matter of allowing any catalogued pamphlet or volume to be taken from either of the libraries for any purpose, but shall decline to permit any such loan unless authorized in writing so to do by the Chairman of the Committee or the Secretary of the society to which the pamphlet or volume belongs. But a duplicate may be thus loaned at the discretion of the Librarian directly responsible."

Librarians and Special Services

The resignation of Miss Josephine T. Bragg after several years of service as Librarian, resulted in the engagement of Miss Jessie R. Hammett of Brooklyn, who began her work about the first of January and has made many friends by her diligence in personal effort to bring about the transfer of the Library with the least possible interruption of its availability, her enthusiasm in formulating new methods to adapt it to its new surroundings and increase its usefulness, and the readiness with which she has become acquainted with its frequenters and their necessities. Thus far an assistant, Miss Gladys Byrd, has been employed to expedite the completion of new arrangements.

The thanks of the Committee are due to Charles L. Clarke, one of our members, who has made valuable contributions to the plans for enlarge-ment, radical rearrangement and protection of the books during the transition period, and has served as secretary of the Committee and otherwise frequently assisted the members of the Committee, particularly in the work of furnishing the business offices of the Institute on the tenth floor, with which special duty the Committee was entrusted by the Board of Directors early in the present Institute year, in preparation for the occupancy which was fully accomplished shortly before the formal dedication.

Of the $4000 appropriated for this purpose, the Committee expended $1195.81 for carpets, linoleum and other floor coverings, and $2614.41 for furniture of the office, reception, editorial, stenographers' and Board rooms; thus leaving a balance now standing unexpended of $189.78.

Respectfully submitted.

The Library Committee,
CHAS. F. CHANDLER
CHAS. A. TERRY
EDWARD CALDWELL
FRANK N. WATERMAN
W. J. JENKS, *Chairman.*

CONSTITUTION

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

[*Incorporated March* 16, 1896.]

[*Adopted May* 13, 1884. *Amended December* 8, 1885, *September* 27, 1892, *May* 15, 1894, *March* 16, 1896, *May* 21, 1901, *and May* 21, 1907.]

ARTICLE I.

1. The name of this association is the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

2. Its objects shall be the advancement of the theory and practice of Electrical Engineering and of the allied Arts and Sciences and the maintenance of a high professional standing among its members. Among the means to this end shall be the holding of meetings for the reading and discussion of professional papers and the publication of such papers, discussions and communications as may seem expedient.

ARTICLE II.

MEMBERSHIP.

3. The membership of the INSTITUTE shall consist of Honorary Members, Members and Associates. Members and Associates shall be equally entitled to all of the rights and privileges of the INSTITUTE, excepting that Members only shall be eligible to the offices of President and Vice-President, and shall be entitled to a diploma. Honorary Members shall be entitled to all the rights and privileges of the INSTITUTE, except the right to vote for officers and to hold office.

4. A Member shall be not less than twenty-seven years of age and shall be:

a. A Professional Electrical Engineer; or

b. A Professor of Electrical Engineering; or

c. A person who has done important original work of recognized value to electrical science; or

d. A person duly qualified as an engineer in an allied branch of engineering, and who, for a period of two years, has had responsible charge of electrical engineering work and whose professional record indicates that he is competent to design, as well as direct, electrical engineering works.

5. To be eligible to the grade of Member as a professional Electrical Engineer, the applicant shall have been in the active practice of his profession for at least five years; he shall have had responsible charge of work for at least two years, and shall be qualified to design as well as direct electrical engineering works. Graduation from a School of Engineering of recognized standing shall be considered the equivalent of one year's active practice.

6. To be eligible to the grade of Member as Professor of Electrical Engineering, the applicant shall have been in responsible charge of a course of Electrical Engineering at a college or technical school of recognized standing, for a period of at least two years.

7. An Associate shall be a person not less than twenty-one years of age who is interested in, or connected with, the study or application of electricity.

8. Honorary Members may be chosen from among those who have rendered acknowledged eminent service to electrical engineering or its allied sciences.

ARTICLE III.

ADMISSION, TRANSFER AND EXPULSION OF MEMBERS.

9. Honorary Members shall be proposed in writing by at least ten Members, and may be elected only by the unanimous vote of the Board of Directors, a ballot in writing to be forwarded by members absent from the Directors' meeting. The election of an Honorary Member shall be deemed invalid if an acceptance is not received within six months after the date of his election.

10. All applications for admission to the INSTITUTE shall be made for the grade of Associate, in a form prescribed by the Board of Directors, and shall refer to at least three (3) Members or Associates. In applying for admission to the INSTITUTE as Associate, any person may also apply at the same time for immediate transfer to the grade of Member. Such

application for transfer may also be made at any time subsequent to election as Associate.

11. An application for transfer from the grade of Associate to that of Member shall be made in a form prescribed by the Board of Directors, and shall embody a full record of the general technical education of the candidate and of his professional career. It shall be signed by the applicant and shall refer to at least five Members who know him personally and are familiar with his work. Each of these references shall be requested by the Secretary to fill out a prescribed confidential form, to be addressed to the Board of Directors. No such applications for transfer shall be considered until at least five favorable replies have been received. The Board of Directors, or the Board of Examiners, in the event of failure of replies or receipt of unfavorable replies, may call upon the applicant to furnish additional names. Should an applicant for transfer certify that he is not personally known by five Members, the Board of Examiners may accept, for the deficiency, references to professional engineers of standing.

12. The reference to Members to whom an applicant is personally known may be waived in case of foreign applications; but the applicant shall in that case refer to at least two professional engineers of recognized standing.

13. The Secretary shall issue at stated intervals to each Member and Associate whose address is known, a list of new applications for admission to the INSTITUTE, with the request that the Members and Associates make written communication to the Board of Directors, in case of objection to any of the candidates named. The Board of Directors shall not act upon any name until at least twenty days after the date of issue of said list.

14. All elections as Associates, and transfers to the grade of Membership, shall be by vote of the Board of Directors; two negative votes shall exclude a candidate.

15. The Board of Directors may refuse to elect or transfer any applicant whose character, reputation or professional conduct would make him, in the opinion of the Board of Directors, an undesirable member.

16. A member of any grade in the INSTITUTE may resign his membership by a written communication to the Secretary, who shall present the same to the Board of Directors; whereupon, if all his dues and other indebtedness have been paid, as

provided in the Constitution and By-Laws, his resignation shall be accepted.

17. Upon the written request of ten or more Members or Associates that, for cause stated therein, a Member or Associate of the INSTITUTE be expelled, the Board of Directors shall consider the matter, and if there appears to be sufficient reason, shall advise the accused of the charges against him. He shall then have the right to present a written defence, and to appear in person or by duly authorized representative before a meeting of the Board of Directors, of which meeting he shall receive notice at least twenty days in advance. Not less than two months after such meeting, the Board of Directors shall finally consider the case, and if in the opinion of the Board of Directors a satisfactory defence has not been made, and the accused member has not in the meantime tendered his resignation, he shall be expelled.

ARTICLE IV.

DUES.

18. The entrance fee, payable on admission to the INSTITUTE shall be five (5) dollars. A fee of ten (10) dollars shall be paid on transfer to the grade of Member, which shall include the fee for a diploma.

19. The annual dues shall be fifteen (15) dollars for Members and ten (10) dollars for Associates.

20. Honorary Members shall be exempt from all payments.

21. Persons elected after any portion of the fiscal year shall have expired, shall pay dues pro rata for the unexpired quarters of that fiscal year.

22. A Member or Associate in good standing, by the single payment of two hundred (200) dollars, in addition to his entrance fee, shall become exempt from all future payments for dues or transfer fee. The money thus paid shall be invested as a special fund, to be known as the " Life Membership Fund," from which there shall be taken out and appropriated for the general expenses of the INSTITUTE each year until the death or resignation of said Member or Associate, the sum of ten (10) dollars. Upon the death or resignation of any such Member or Associate, the residue from said payment, including the interest thereon, remaining in the said fund, shall be transferred to the general fund of the INSTITUTE.

23. A Member or Associate who has been dropped as delinquent may be reinstated by the Board of Directors upon payment of all back dues, retaining his original date of election, and shall be entitled to a complete file of the published TRANSACTIONS corresponding with said payment, provided the same are available.

ARTICLE V.

OFFICERS.

24. The officers of the INSTITUTE shall be a President, six Vice-Presidents, twelve Managers, a Secretary, and a Treasurer, who shall hold office as follows:

25. The President, the Secretary, the Treasurer, for one year, the Vice-Presidents for two years, and the Managers for three years. The President, Vice-Presidents and Managers, shall not be eligible for immediate re-election to the same office. A Vice-President shall not be eligible for immediate election to the office of Manager. At each Annual Meeting, the President, three Vice-Presidents, four Managers, the Secretary and the Treasurer shall be elected in the manner prescribed below, and their terms of office shall commence on the first of August next succeeding their election.

26. The terms of the Officers elected at the Annual Meeting at which this constitution is adopted, shall begin on the fourth Friday in September following, instead of on the first of August, as provided in Section 25.

27. A vacancy in the office of President shall be filled by the senior Vice-President; a vacancy in the office of Vice-President shall be filled by the senior Manager. Seniority between officers of same rank and date of election shall be determined by the date of their election as Associates. All other vacancies shall be filled by the Board of Directors for the unexpired term. Such succession to office or appointment by the Board of Directors shall not render an officer ineligible for immediate election to the same office.

28. No officer shall receive, directly or indirectly, any salary compensation or emolument from the INSTITUTE, either as such officer or in any other capacity, unless authorized by a vote of a majority of the entire Board of Directors.

29. No officer shall be interested, directly or indirectly, in any contract relating to the operations conducted by the

INSTITUTE, nor in any contract for furnishing supplies thereto, unless expressly authorized by the By-laws or by the unanimous vote of the members of the Board of Directors present at any meeting

ARTICLE VI.

ELECTION OF OFFICERS.

30. During the first week in February of each year, the Secretary shall mail or deliver to each Member and Associate of the INSTITUTE, a list of all Members and Associates, together with a form showing the offices to be filled at the ensuing annual election in May, and containing the names of the incumbents and a copy of sections 30 and 31 of this Article, with the request that nominations be made for the various offices to be filled. These nominations shall not be signed, and shall be enclosed in an envelope, identified on the face by the name of the sender and mailed to the Secretary. To be considered, nominations must reach the Secretary prior to March first. The nomination ballots shall be counted and canvassed by the Committee of Tellers appointed as provided in Sections 34 and 35.

31. The Committee of Tellers shall submit to each member of the Board of Directors prior to the March meeting, a classified list of all nominations received, from which the Board of Directors shall prepare, during the month of March, a complete ticket, to be headed: ' Directors' Nominees," containing the names of those whom the Board of Directors deem best suited for the offices falling vacant; provided that upon the request of two Directors at the meeting at which the " Directors' Nominees " ticket is prepared, the name of a second nominee for President shall be placed on the ticket, selected from the four names receiving the highest number of nomination votes for President, and provided further, that upon the request of two Directors at the same meeting, the names of one or more additional nominees for Vice-President, and upon like request, the names of one or more additional nominees for Manager shall be placed upon the ticket. The names on the Directors' Nominees ticket shall be listed in the order of the number of nomination votes received, beginning with the highest number. This ticket shall be printed on the same sheet with a second list, headed " General Proposal List," containing all the eligible names pro-

posed, and the number of votes cast for each; provided that no name shall appear which shall not have received at least three per cent. of the entire number of votes cast.

32. The voting for officers shall be restricted to the names of the " Directors' Nominees " and the names on the General Proposal List provided for in section 31 of this Article. This List, together with an envelope on which shall be printed the title of the INSTITUTE, the name and address of the Secretary and the words " Official Voting Envelope—Enclosing a Ballot Only," shall be mailed by the Secretary not later than the first day of April, to every Member and Associate, together with a copy of sections 32 and 33 of this Article; provided that any qualified Member or Associate not having a ballot and envelopes shall be entitled to obtain them from the Secretary at any time before the first day of May.

33. All names voted for shall be written, printed or otherwise marked on a single ticket or ballot, which shall be enclosed in a sealed, unmarked and unidentified inner envelope of any suitable character, which shall in turn be enclosed either in the " Official Voting Envelope " (received from the Secretary), or any other envelope, marked on its face, " Non-Official Voting Envelope—Enclosing a Ballot Only." The outer envelope of either class shall be identified by the name of the sender on its face, shall be sealed, and in order to be counted, shall reach the Secretary not later than the first day of May. The Secretary shall preserve, unopened, for ninety days, all ballots received after the first day of May.

34. The President, at the Directors' meeting to be held in February, shall appoint, subject to the approval of the Board of Directors, five Members or Associates, not members of the Board of Directors, to constitute the Committee of Tellers; should this Directors' meeting not be held, the President, previous to the twenty-first of February, shall appoint this Committee by letter to the Secretary, who shall notify the members thereof.

35. Any Member or Associate who shall deliver to the Secretary on or before the first day of March, a written petition signed by at least twenty Members or Associates, stating their desire that he be a member of the Committee of Tellers, shall also be a member of that Committee; provided that the aforesaid signatures shall not have appeared on another similar petition.

36. The Committee of Tellers shall meet at the office of the INSTITUTE as soon after the first day of May as possible, and shall receive, unopened, all ballots from the Secretary, who shall also make to it a written report of the number of ballots received on and before, and after, the first day of May. It shall forthwith proceed, in secret, to count the vote, and shall prepare and sign in duplicate a report of the results of the vote, which shall be sealed, and of which one copy shall forthwith be filed with the Secretary, and of which the other copy shall remain in possession of the Chairman of the Committee who shall hand this report to the presiding officer at the ensuing Annual Meeting. In the absence of this report by the Chairman of the Committee, the Secretary shall produce the duplicate copy, and hand the same to the presiding officer of the meeting. The presiding officer shall cause the report to be read, at the first session of the Annual Meeting and shall declare duly elected the eligible persons receiving the greatest number of votes for the respective offices.

ARTICLE VII.

MANAGEMENT. DUTIES OF OFFICERS AND COMMITTEES.

37. The affairs of the INSTITUTE shall be managed by a Board of Directors under this Constitution and the general provisions of the laws under which it is incorporated. The Board of Directors shall consist of the President, two Junior Past-Presidents, the Vice-Presidents, the Managers, the Secretary and the Treasurer.

38. The Board of Directors shall have such powers and duties as are prescribed by statute for a Board of Directors.

39. The Board of Directors shall direct the investment and care of the funds of the INSTITUTE, shall make appropriations for specific purposes, shall pass upon all applications for admission or for transfer, shall act upon all questions of expulsion of members, shall appoint all employees and fix their salaries, and in general shall direct the business of the INSTITUTE, either itself or through its officers and committees.

40. The Board of Directors shall prepare and adopt a series of By-laws which shall govern its procedure and that of the Committees, under this Constitution. Such By-laws shall be adopted or may be amended by a concurring vote of not less than twelve (12) members of the Board of Directors; provided,

that the text of a proposed By-law or amendment shall be furnished to each member of the Board of Directors at least ten days before the meeting at which a vote on the same will be taken.

41. The President shall have general supervision of the affairs of the INSTITUTE, under the direction of the Board of Directors. He shall preside at the meetings of the INSTITUTE, and of the Board of Directors at which he may be present, and shall be *ex-officio* member of all committees. He shall deliver an address at the Annual Convention. The Vice-Presidents, or in their absence, the Managers, in order of seniority, shall preside at meetings of the INSTITUTE and the Board of Directors in the absence of the President, and shall discharge his duties in case of a vacancy in the office. The President shall appoint the standing committees of the INSTITUTE. He may also appoint special committees from time to time.

42. The Secretary shall be the executive officer of the INSTITUTE under the direction of the President and the Board of Directors, He shall attend all meetings of the INSTITUTE and of the Board of Directors, and record the proceedings thereof. He shall collect and deposit, subject to the order of the Treasurer, all moneys due the INSTITUTE, reporting such deposit to the Treasurer, who shall receipt for the same. He shall personally certify the accuracy of bills or vouchers on which money is to be paid, and shall draw and countersign all checks, and these shall be signed by the Treasurer when such drafts are known to him to be proper, and duly authorized by the Finance Committee and in accordance with warrants executed by the Secretary. He shall have charge of the books and accounts of the INSTITUTE. He shall present annually to the Board of Directors a balance sheet, and from time to time shall furnish such statements as may be required. He shall conduct the correspondence of the INSTITUTE, and shall keep full records. He shall be in responsible charge, under the President and the Board of Directors, of all the property of the INSTITUTE. He shall, with the approval of the Board of Directors, employ such clerical force as may be necessary and shall be responsible for the work of all employees of the INSTITUTE. He shall perform such other duties as may be assigned to him. His entire time must be devoted to the affairs of the INSTITUTE, unless otherwise authorized by the Board of Directors. He

shall be paid a salary to be fixed by the vote of a majority of the entire Board of Directors.

43. The Treasurer and the Secretary shall invest such funds as may be ordered by the Board of Directors. They shall also pay bills when audited by the Finance Committee and approved by the Board of Directors. The Treasurer shall make an annual report and such other reports as may be prescribed

44. The Board of Directors may delegate any or all of its powers to an Executive Committee of seven members, consisting of the President, the Secretary, and the Treasurer, *ex-officio*, and four other members of the Board of Directors, which committee shall conduct the affairs of the Board of Directors between its meetings.

45. The Board of Directors or the Executive Committee (subject to the direction of the Board) may at any time authorize any officer, director, or other person to perform any acts or functions, which in the Constitution or By-laws may be prescribed to be performed by any specified officer or other person, whenever by reason of death, absence, disability or other cause, sufficient ground therefor shall appear to the Board or Executive Committee.

46. The Standing Committees to be appointed by the President as specified in section 41 shall be the following:

A Finance Committee of three members.
A Library Committee of five members.
A Meetings and Papers Committee of five members.
An Editing Committee of three members.
A Board of Examiners of five members.
A Sections Committee of five members.
A Standards Committee of nine members.
A Code Committee of seven members.
A Law Committee of five members.

The Board of Directors may appoint auxiliary members to any committee. The members of the Finance Committee shall all be members of the Board of Directors. All other standing committees shall include at least one member of the Board of Directors. All members of the Board of Examiners shall be Members of the INSTITUTE. All committees shall be directly responsible to the Board of Directors, and shall act under its directions. The Board of Directors may, at any time, at its own discretion, remove any or all members of any committee and appoint others. The terms of the members of all standing and special committees shall terminate at the close of the first meeting of the Board of Directors following the Annual Meeting.

47. All official communications of committees to the Board of Directors shall be made through the Secretary unless otherwise specially ordered by the Board of Directors.

48. In addition to the duties and powers hereinafter ascribed to committees, these committees shall perform such other duties, and shall have such other powers, as may be specified in the By-laws, or as may be delegated to them by the Board of Directors.

49. The Finance Committee shall have direct supervision of the financial affairs of the INSTITUTE. It may employ an expert accountant to assist in auditing the accounts. It shall approve all bills before payment, and shall make recommendations to the Board of Directors regarding the investment of moneys, and all specific appropriations. No payments other than for routine office expenses shall be made by the Secretary or Treasurer except upon the authorization of the Finance Committee.

50. The Library Committee shall have general supervision of the Library of the INSTITUTE. The committee shall make recommendations to the Board of Directors with reference to the Library, and shall direct expenditures for books or other articles for the same, of such sums as may be appropriated for these purposes.

51. The Meetings and Papers Committee shall arrange for the meetings of the INSTITUTE, and for the preparation and discussion of the papers to be presented before the INSTITUTE. The committee shall decide all questions regarding the acceptance or rejection of any paper submitted for presentation before the INSTITUTE, and all questions regarding the publication of papers presented before the INSTITUTE or any of its Sections.

52. The Editing Committee shall edit all discussions of the papers presented at any meeting of the INSTITUTE, and all communications in reference thereto, and shall decide all questions regarding the publication of discussions and communications in the PROCEEDINGS and TRANSACTIONS of the INSTITUTE or otherwise.

53. The Board of Examiners shall pass upon the qualifica-

tions of all applicants for election or for transfer, whose applications have been received by the Secretary, and which are in conformity with Sections 10, 11, and 12 of Article 3, and it shall report its findings to the Board of Directors for action.

54. The Sections Committee shall have the general supervision and management of the Sections and Branches of the INSTITUTE. The committee shall confer with the Sections and Branch officers, and it shall consider, investigate, and make reports and recommendations to the Board of Directors for action upon all matters regarding or involving the interests and the welfare of Sections and Branches, or the relations between these organizations and the INSTITUTE.

55. The Standards Committee shall consider and investigate all matters relating to units and standards appertaining to or applicable in electrical engineering and in the allied arts and sciences. The Committee shall make reports and recommendations to the Board of Directors for action thereon.

56. The Code Committee shall consider and investigate all matters relating to the formulation of rules for the protection of persons and property against fire and other hazards in connection with electrical installations and equipments, and shall confer with similar committees of other bodies regarding the same. The Committee shall make reports and recommendations to the Board of Directors for action thereon.

57. The Law Committee shall consider and investigate all matters relating to the Constitution and By-laws of the INSTITUTE, the duties and jurisdiction of its officers and committees, its legal status and responsibilities and like legal and cognate questions; also all other matters referred to it by the Board of Directors, the President or the Secretary. The Committee shall make reports and recommendations to the Board of Directors for action thereon. The Committee may consult legal and technical counsel with reference to any question before it.

58. The Board of Directors may, at its discretion, appoint Local Honorary Secretaries to represent the INSTITUTE in foreign countries. Such appointments shall be made for a period of two (2) years and may be renewed.

59. The following numbers shall constitute a quorum of the Board of Directors:

For all business prescribed by statute for a Board of Directors

—twelve members or such larger number as the statute may require.

For expulsion of Members—fifteen members.

For all other business—five members.

60. Unless otherwise specifically provided in this Constitution, the action of the Board of Directors shall, in all cases, be determined by the concurring vote of a majority of the members present, providing there exists the quorum required for the particular business.

ARTICLE VIII.

MEETINGS.

61. The Annual Meeting of the INSTITUTE shall be held in the city of New York, beginning on the second Friday in May, when a report of the proceedings of the INSTITUTE for the past fiscal year shall be furnished by the Board of Directors. This report shall be verified by the President, Treasurer and Secretary and approved by the Board of Directors. It shall show: the whole amount of real and personal property owned, where located, where and how invested; the amount and nature of the property acquired during the past fiscal year and the manner of its acquisition; the amount applied, appropriated or expended during the year, and the purposes, objects or persons to or for which such applications, appropriations or expenditures have been made; the names and places of residence of persons who have been admitted to membership in the INSTITUTE during such year; and all other facts bearing upon the status of the INSTITUTE. This report shall be filed with the records of the INSTITUTE and an abstract thereof entered in the minutes of the Annual Meeting. The reports of all officers and of the standing committees shall be presented at the Annual Meeting, and the vote for officers for the ensuing year shall then be announced. In addition to the above, professional papers and the discussions thereof arranged for by the Meetings and Papers Committee may be presented, and any other business may be brought before and transacted, at this meeting.

62. There shall be held outside of the city of New York not later than August first an Annual Convention of the INSTITUTE, for the presentation and discussion of professional papers, and for the transaction of other business not affecting the organization or policy of the INSTITUTE. All questions affecting the

organization or policy of the INSTITUTE may be brought up for discussion at this Convention, and may be referred by a majority vote to the Board of Directors, with recommendations. The time and place of such Convention shall be fixed by the Board of Directors.

63. Special meetings of the INSTITUTE for the transaction of business may be called by the Board of Directors at any time, by written notice stating the specific object thereof mailed to each Member and Associate at least thirty (30) days prior to the date of said meeting.

64. Other meetings of the INSTITUTE may be held at such times and places as the Board of Directors shall select, at which no business affecting the organization or policy of the INSTITUTE shall be transacted. Notice of all meetings specified in this Article of the Constitution shall be sent by mail, or otherwise, to all Members and Associates, at least ten days in advance.

ARTICLE IX.

INSTITUTE SECTIONS AND BRANCHES.

65. Whenever, in the judgment of the Board of Directors, a sufficient number of Members and Associates shall petition, in writing, these members may form, subject to the Constitution and all By-laws and regulations which may be hereafter prescribed by the Board of Directors a Section organization for the purpose of more effectually carrying out the aims of the INSTITUTE.

66. Any Member or Associate may become a member of such Section, but a Member or Associate shall be entitled to vote, or hold office, in one Section only.

67. The officers of each Section shall consist of a Chairman, a Secretary, and such other officers as each Section may find desirable. These officers shall be elected by the votes of the Members and Associates of that Section, in the manner provided in the Section By-laws. The election of any Member or Associate as a Section officer, shall not debar him from election or appointment to any other office in the INSTITUTE.

68. The Chairman of the Section shall perform the duties usually devolving upon the Chairman of any organization, and in addition shall be *ex-officio* a member of the Sections Committee of the INSTITUTE. He shall have the privilege

of appearing before the Board of Directors at any meeting, on giving due notice of his intention to do so, for the purpose of conference with the Board of Directors, in regard to any matters pertaining to the affairs of the INSTITUTE in his Section. The Chairman shall perform such other duties and shall have such other powers as may be delegated to him by the Board of Directors.

69. The Secretary shall report the Proceedings of the Section to the Secretary of the INSTITUTE; he shall, in general, discharge the duties of a Secretary both to the Section itself and in its relation to the INSTITUTE; he shall perform such other duties as may be prescribed in the Section By-laws, or in the By-laws of the INSTITUTE, or delegated to him by the Board of Directors.

70. Each Section may have the privilege of being represented at the Annual Convention, by an official delegate, who shall be the Chairman of that Section, or, in his absence or inability to attend, by an alternate delegate selected by the Section. The official delegate attending the Annual Convention may have his expenditures for transportation refunded by the INSTITUTE, as provided in the By-laws.

71. The Sections may hold meetings at such times and places as may be determined by their officers, for the purpose of carrying on their work.

72. Any Section may adopt for its own government such By-laws to be known as " Section By-laws " as it may find expedient, provided that no provision thereof shall be incompatible with the Constitution or the By-laws of the INSTITUTE.

73. University Branches may be formed and Student meetings may be held as provided in the By-laws.

74. Sections and Branches may be dissolved in the manner specified in the By-laws for failure to comply with the Constitution and By-laws of the INSTITUTE.

ARTICLE X.

GENERAL.

75. A quorum of the INSTITUTE at the Annual Meeting shall consist of not less than five per cent. of the total number of Members and Associates, present in person or by proxy. The same number shall constitute a quorum for the transaction of

business at the Annual Convention and at special meetings called as provided in section 63.

76. Every Member or Associate entitled to vote at any meeting may so vote by proxy, signed by the Member or Associate, and filed with the Secretary before the meeting at which it is to be voted. No proxy shall be valid after the expiration of eleven (11) months from the date of its execution, unless the Member or Associate executing it shall have specified therein the length of time it is to continue in force, which shall be for some limited period. Every proxy shall be revocable at the pleasure of the person executing it.

77. The Committee of Tellers named in Article VI., sections 34–35, shall be considered a proxy committee for the definite purpose of formally voting, at the annual election, letter ballots named in Article VI., sections 32–33, and canvassed by them as stated in section 36.

78. The fiscal year of the INSTITUTE shall terminate with the thirtieth day of April.

ARTICLE XI.

AMENDMENTS.

79. Amendments to this Constitution may be proposed by means of a petition signed by not less than one hundred (100) Members or Associates and received by the Secretary not later than February first; or by means of a Resolution adopted by the Board of Directors not later than February first. Such proposed amendment or amendments shall be submitted to legal counsel by the Board of Directors, and if, in the opinion of such counsel, they are in accordance with the laws under which the INSTITUTE is organized, a copy shall be mailed, with a letter ballot, to each Member and to each Associate, not less than sixty (60) days before the Annual Meeting.

80. Votes, to be considered, shall be received by the Secretary not later than one week before the Annual Meeting. The Secretary shall hand these votes unopened to the Committee of Tellers, which shall count such votes and make a sealed report to the Board of Directors in duplicate, of which one copy shall forthwith be filed with the Secretary, and of which the other copy shall remain in possession of the Chairman of the Committee, who shall hand this report to the presiding officer at the annual meeting. In the absence of this report by the

Chairman of the Committee the Secretary shall produce the duplicate copy and hand the same to the presiding officer of the meeting. The presiding officer shall then cause the report to be read. If the total vote be not less than thirty per cent. (30%) of the total membership of the INSTITUTE, and if seventy-five per cent. (75%) or more of all the Members and Associates voting shall declare themselves in favor of the proposed amendment or amendments, the same shall become a part of the Constitution.

81. Amendments shall take effect thirty (30) days after their adoption, but officers of the INSTITUTE at the time any amendment becomes effective shall continue in office until the end of the terms for which they were elected.

82. The Secretary shall print copies of the amendments as soon as practicable after adoption, and distribute the same to Members and Associates.

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